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Tree Growth on the Snake River Floodplain, Jackson Hole, Wyoming: A Dendrochronology Project

by Charles A. Reher, Laura L. Scheiber

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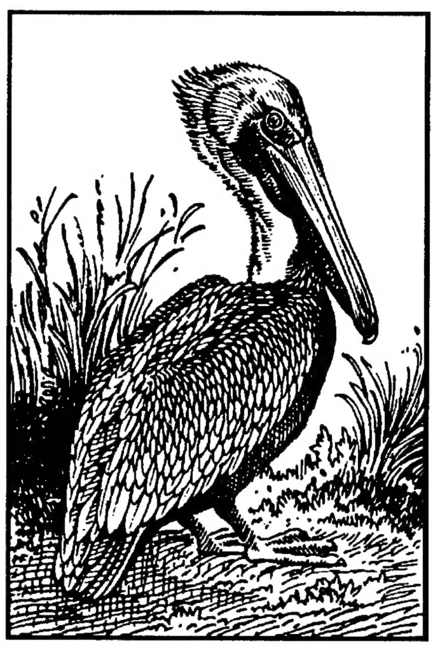


November 1995 – Final Report

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The following two letters used as part of the number designating technical reports of research published under the Wetlands Research Program identify the area under which the report was prepared:

	Task		Task
CP	Critical Processes	RE	Restoration & Establishment
DE	Delineation & Evaluation	SM	Stewardship & Management

Wetlands Research Program

Technical Report WRP-RE-9
November 1995

Tree Growth on the Snake River Floodplain, Jackson Hole, Wyoming: A Dendrochronology Project

by Charles A. Reher, Laura L. Scheiber

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Final report

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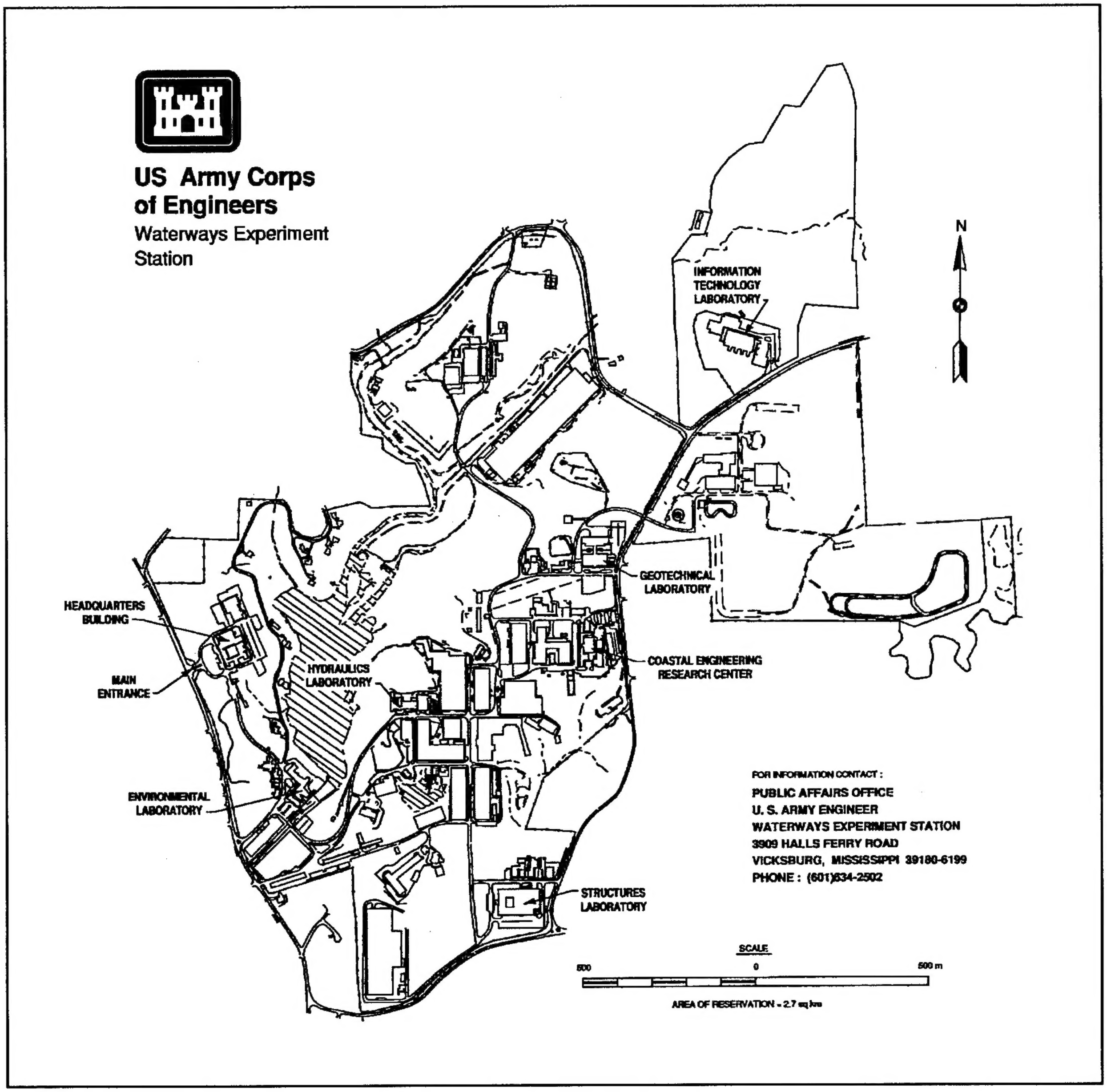

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Tree Growth in Floodplains

Tree Growth on the Snake River Floodplain, Jackson Hole, Wyoming: A Dendrochronology Project (TR WRP-RE-9)

ISSUE:

The establishment of levees and the disturbances that accrue after they are built affect the local tree growth rates. Information is needed concerning tree growth rates under varying floodplain conditions, such as areas with flood control levees versus no levees, disturbed by flooding or grazing versus no disturbance

RESEARCH:

Measurable radii from trees in four different study sites were collected, cured, and analyzed. The sites are a representative set of Snake River Floodplain contexts, organized around a continuum of different amounts of human and natural effects on the floodplain ecosystem. The sites are comparable in terms of substrate geology, soil types and depths, elevation, slope, distance to river, and depth of the water table.

SUMMARY:

Tree ring counts and width measurements allowed the establishment of individual tree ages, growth patterns, growth rates, and other needed information. A clear and statistically significant difference in tree growth exists between the four study sites. A stand-age effect contributed to the differing growth rates as did competition from developing canopy coverage and understory density. These are in turn greatly affected by the establishment of levees, or the lack of them, and by livestock grazing. Levee construction has inhibited groundwater flow, replenishment of nutrients through seasonal flooding, and high velocity floods and channel movement that reduces understory competition and builds new growth sites for regeneration. Increasing understory density in leveed, undisturbed sites eventually retards tree growth rates, while grazing increases the density of grazing-tolerant species that also retard growth rates. Clear differences exist between evergreen and cottonwood species, with cottonwoods being more sensitive to climate variability and disturbance.

AVAILABILITY OF REPORT:

This report is available on Interlibrary Loan Service from the U.S. Army Engineer Waterways Experiment Station (WES) Library, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199, telephone (601) 634-2355.

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Preface

The work described in this report was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Wetland Restoration, Protection, and Establishment of Wetlands Task Area of the Wetlands Research Program (WRP). The work was performed under Work Unit 32761 for which Dr. Mary C. Landin, U.S. Army Engineer Waterways Experiment Station (WES), Environmental Laboratory (EL), was the Technical Manager. Ms. Denise White (CECW-ON) was the WRP Technical Monitor for this work.

Mr. David Mathis (CERD-C) was the WRP Coordinator at the Directorate of Research and Development, HQUSACE; Dr. William L. Klesch (CECW-PO) served as the WRP Technical Monitors' Representative; Dr. Russell F. Theriot (CEWES-EP-W) was the Wetlands Research Program Manager. Dr. Mary C. Landin (CEWES-ER-W) was the Task Area Manager.

Participants in the study, in addition to the authors, included Mr. Lonnie Mettler of the U.S. Army Engineer District, Walla Walla, Washington (CENPW) and Mr. Stan Anderson, Director of the University of Wyoming/ U.S. Fish and Wildlife Service Cooperative Research Unit. The Walla Walla District, in coordination with WES, and through the assistance of the above Cooperative Research Unit, procured the services of the University of Wyoming, Cheyenne, for the work described in this report. This was done under an existing Cooperative Agreement (No. 14-48-0009-93-1542, Work Order No. 126). The authors of the report were Dr. Charles A. Reher and Dr. Laura L. Scheiber, Department of Anthropology, University of Wyoming. Field and laboratory assistance were provided by Mr. Michael Peterson, Ms. Sandra Reher, and Mr. Daniel Bach. Mr. Robert Lazor of WES (CEWES-EP-W) was instrumental in facilitating the above initial coordination with the district to achieve the procurement effort. The report was technically reviewed by Dr. Mary C. Landin and Dr. Mary Davis, EL. Mr. L. Douglas Whitaker, EL, provided editorial support.

The report was written under the direct supervision of Mr. Hollis H. Allen, Acting Chief, Stewardship Branch and principal investigator for the study, and under the general supervision of Dr. Robert M. Engler, Chief, Natural Resources Division, and Dr. Edwin A. Theriot, Assistant Director, EL, and Dr. John Keeley, Director, EL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
inches	25.4	millimeters

1 Introduction

The Snake River Project

The Department of Anthropology study on the Snake River floodplain involved four main goals:

a. Fieldwork to recover 115 measurable radii from 56 trees during field work in September 1993 (primarily increment cores from living trees but also several deadfall slabs).

b. The design and construction of a new IBM-compatible computerized measuring system, along with programming new software and obtaining or refining existing software (also during the fall of 1993).

c. Sample curation and preparation, followed by measurement and other basic analysis during the winter of 1993/1994 (on the order of 7,500 individual measurements).

d. Detailed sample analysis and report preparation during the late winter and spring of 1994.

Site and Sample Selection

The dendrochronology samples came from four study sites which ranged from the southern portion of Grand Teton National Park to just to the west of the town of Jackson, a distance of about 16 km in a north-south direction along the meandering Snake River channel (Figure 1). These four sites had been previously selected and studied by the Wyoming Cooperative Fisheries and Wildlife (WCFW) Research Unit to obtain species type, canopy coverage, and other botanical data.

The WCFW Research Unit provided the Department of Anthropology investigators with descriptions of the study sites and with landownership information, canopy type/density data, copies of aerial photographs, and other materials. This detailed information, including field notes on how specific

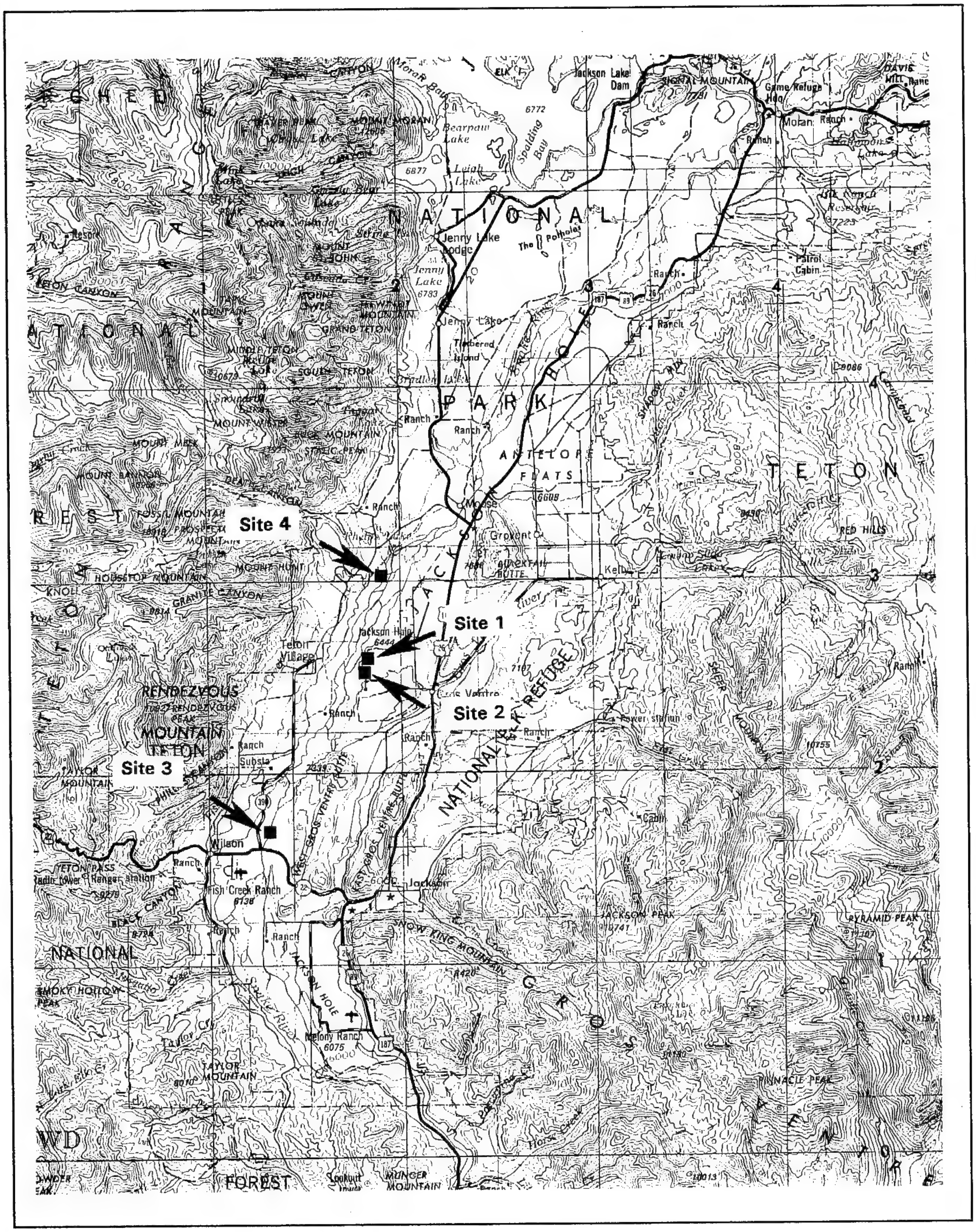


Figure 1. Location of Snake River dendrochronology study areas in Jackson Hole (Continued)

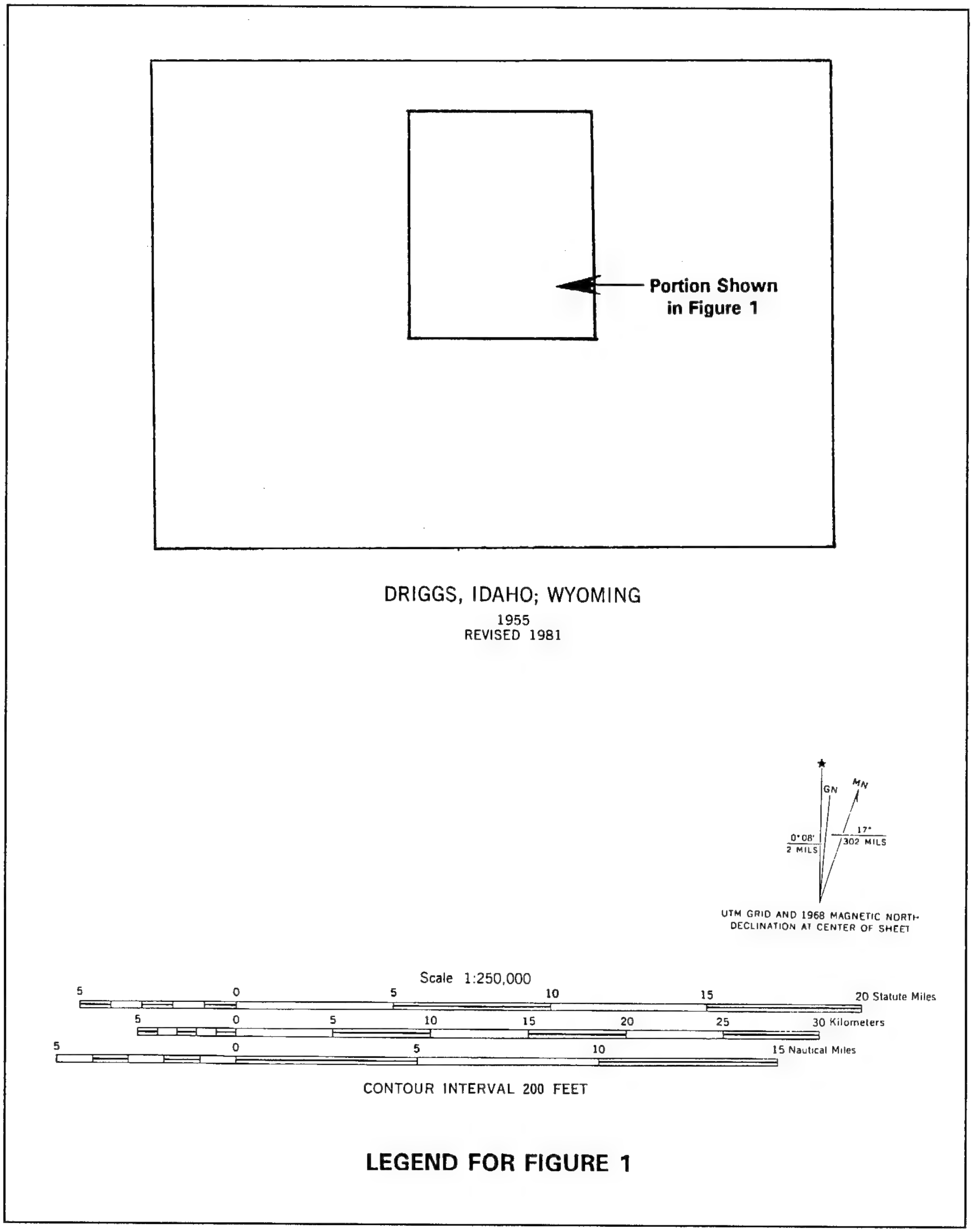


Figure 1. (Concluded)

sampling transects were flagged, facilitated sampling the exact same locations as the WCFW Research Unit study.

The four study sites were a representative set of Snake River floodplain contexts, organized around a continuum of different amounts of human and natural effects on the floodplain ecosystem, e.g., flood control levees versus no levees, disturbed by flooding or grazing versus no recent disturbance, etc. Beyond that, the four study sites were very comparable in terms of substrate geology, soil types and depths, distance to the river and depth of the water table, elevation, slope and aspect.

The WCFW Research Unit transects tended to start adjacent to the river bank or levee and run perpendicularly back into the floodplain, while this sampling was based more on judgmental extraction of specimens from within a rectangle large enough to incorporate these transects. This strategy included all or most suitable evergreens, as well as a large number of very comparable cottonwoods, so that the dendrochronological results are representative of the trees on each type of floodplain site.

The tree-ring study also utilized four tree species (lodgepole pine, subalpine fir, narrowleaf, and black cottonwood) to ensure that the effects of different site contexts were not masked by species-specific response patterns (as discussed below). Different tree ages were also selected, although most concentration was on the relatively mature trees which provide the most consistent data and which provide longer measurement sequences. (Different age-grade subsets or subsets based on actual years could be extracted from these main sequences, e.g., growth for trees 20 to 40 years old, or for all tree growing during the period 1950-1970). Very young trees were also selected to provide comparisons of recent sapling growth rates and because the limited evergreen samples available at some of the study sites consisted of evergreens from this age class.

Conditions of Tree Growth

All study sites were comparable in terms of distance from the Snake River. Low swales in old meander scars and other low-lying zones invariably had pools of surface water, indicating that the water table was only 1 m or less below the current ground surface. The shallow soils of sandy loam and humus were perched on alluvial deposits made up of large cobbles and gravels typical for the Snake River floodplain.

Although they were high in general, it was expected that water tables fluctuate during the growing season sufficient to have an effect on tree growth. Similarly, the water table could vary enough between wet and dry years to have a discernable effect on ring width, although floodplains tree stands still would not be "sensitive" to the point of making them the best sort of climatic indicators. Temperature fluctuations, especially with regard to general growing

season length and coolness, and with regard to unseasonably severe frosts could also be expected to have an effect on all of the study sites. Competition for soil nutrients, especially as related to understory and overstory density would also be a factor.

In more detail, two factors were expected to contribute to variability in tree growth rates in the study sites:

a. Exogenous and endogenous factors that affected all of the tree stands at all of the study sites relatively equally.

b. Exogenous and endogenous factors that were expected to differ between the sites because of the factors just mentioned (cf. Cook, E. 1992).

More specifically, an example of the tree growth variability common at all sites would be:

a. Exogenous, stand-wide seasonal fluctuation in temperature and moisture regimes and other factors effecting floodplain tree stands relatively equally.

b. Endogenous factors which affected individual trees within a stand but still the type of "scattered" conditions through all of the stands that would allow them to be "averaged out" by comparing large sets of measurements (for example slowed growth from canopy shading followed by a "canopy release" growth spurt when the tree attained a certain height, or when a large tree toppled and left a gap in the canopy).

Tree growth variability, which would not be shared because of differences in site context, might be expected to include such things as lower growth rates due to:

a. Less available soil moisture during early summer, or less deposition of new nutrient-laden sediment across a given set of decades, caused by lack of annual flooding behind levees.

b. Increased interspecies competition for soil moisture and nutrients from crowding of both understory and overstory canopy (e.g., when floods did not periodically strip away some annuals, shrubs, and tree seedlings).

Conversely, increased growth rates might come from factors such as:

a. Flood events of a type which deposited blankets of nutrient-rich, fine sediment.

b. More catastrophic flooding or other disturbance such as overgrazing of understory shrubbery and tree seedlings, either of which could lower

competition by reduced understory and canopy density (cf. Baker 1990).

It is important to note that all such factors take decades to play out. Sorting out such specifics could be done with a larger, more intense dendrochronological project, but such detail was beyond the scope of this study. However, it was assumed that tree growth at the study sites could be ranked, and that some suggestions could be offered about specific factors contributing to this ranking.

Sample Analysis

Laboratory preparation involves a long, very tedious sequence of drying cores, manufacturing grooved, wooden core holders, and mounting the cores on them, followed by another long sequence of sanding, polishing and/or slicing, and staining the individual specimens. Subsequent analysis consists primarily of deriving individual tree ages through ring counts and of obtaining tree-ring width measurements to the nearest hundredth-millimeter by using a computer-based optical rotary encoder incremental measuring device. Ring counts and width measurements provided information for the establishment of individual tree ages, growth patterns, growth rates, and other needed information.

After one to several radii were measured for each tree, measurements were compared, refined, and verified using a variety of macroscopic, microscopic, and statistical verification procedures. These measures and counts resulted in detailed descriptive documentation of individual trees, very useful for any future investigations in the area. The measures and counts also resulted in the establishment of study site age structure, graphical representation of growth patterns, calculation of very precise growth rates, and other necessary data. More intensive comparisons of growth rates then proceeded on the basis of these data.

Comment on Limitations of This Study

Documentation and comparison of basic tree growth rates were the sole purposes of the study. This study is intended only to provide basic background and to explain relevant concepts. Further, as this study is a small adjunct to a larger effort, no real detail is provided on the climate, geology, and hydrology of the Jackson Hole area.

More specific explanations of the causes of dendroecological variation than are offered would require more work by the University of Wyoming (UW) dendrochronology lab, along with more botanical expertise and work by personnel more familiar with Snake River flood control history. Other relevant analyses possible with the current data were beyond the scope and budget for

this project (e.g., climatic reconstruction which would contribute to a much more precise statement about the conditions and causes of tree growth). The data provided are sufficient for project supervisors to expand upon tentative conclusions.

Some dendrochronological crossdating was an automatic result of basic verification of measurements and tree ages, but there was no attempt to establish the final, averaged "master sequence" needed for detailed climatic reconstruction or for the crossdating of older specimens of unknown age, as is done in many dendrochronological studies. To some extent, the pre-selection of the study sites ruled out a more standard collection of the type of tree growth sites best suited for purposes such as climatic reconstruction.

Along the same lines, intensive, multivariate autoregressive modelling based on streamflow data could not be used to establish stand generation histories for larger floodplain areas or to search out the specific climatic factors responsible for such stand regeneration.

Data Documentation

Data sets were documented in a fashion similar to current standards for dendrochronology. This material was produced during the analysis, and it was thought that the material would be useful for future applications in the study of Jackson Hole. The documentation also allows for an intense professional evaluation of the conclusions reached herein.

The documentation was produced by several main areas of concentration. Some brief speculations about tree-stand age structure, stand establishment, riparian succession, and species diversity were possible from the determination of tree ages, i.e., ring counts. All other aspects of the analyses, those oriented specifically to assessing growth rates, depended on obtaining actual ring measurements, e.g., tree growth form, defining age-graded growth rate statistics, and the degree of sensitivity in growth response. Ring counts are more commonly used in forestry studies than large measurement, but the Snake River project demonstrates the veracity of this type of analysis.

Results of the Study

In spite of these limitations, the dendrochronological analysis revealed clear and statistically significant pattern differences in tree growth at the four study sites. As noted above, general consistencies in the growth rates can be attributed to the geological substrate, climatic variation, and other primary controlling factors "held constant" by the selection of similar study sites. Remaining differences in growth rates can be attributed to differing conditions at the sites, such as grazing or flood control measures.

The influencing factor of these basic parameters is discussed in more detail in Chapter 4 of this report. Basic analysis for all trees at a site began to reveal clear and major differences in growth rates; then, more refined analysis based on species and age/date brackets followed the leads provided resulting in a more definite understanding of these differences.

As might be expected, a stand age-effect and related successional processes contributed to the growth rates seen, as did competition from developing canopy coverage and understory density. These are in turn greatly affected by the establishment or lack of levees and by livestock grazing and other disturbances that accrue after a levee has been built. Clear differences existed between evergreen and cottonwood species, with the cottonwoods being more sensitive to climatic variability and disturbance. The highest growth rates were found consistently at Site 3 (Prime Property) and Site 4 (Teton Park), while much lower rates clustered at Site 1 (Moulton Property) and Site 2 (Grayson Property). Growth rate differentials were as high as a factor of 1 to 3 orders of magnitude, i.e., a differential as high as 60 to 80 percent between the highest and lowest growth site in some measurements brackets, and never less than 20 to 40 percent in the most comparable brackets.

The interplay of factors causing growth rate differences is complex, but in a basic sense, levee construction has inhibited groundwater flow, replenishment of nutrients through seasonal flooding, and the high velocity floods and channel movement that reduce understory competition and build new growth sites for regeneration. Increasing understory density in leveed, undisturbed sites eventually retard tree-growth rates, while grazing increases the density of grazing-tolerant species that also retard growth rates. Disturbance behind the levee system can lead to extremely consistently high growth rates compared to unleeved areas, but there is some indication that this increased growth is tapering off.

2 Dendrochronology, Dendroclimatology, and Dendroecology

Basic Principles

Though simply counting and measuring tree-rings can provide for the determination of tree age, dating of archaeological specimens, and reconstructing of past climate, many in the public or scientific community seem to have an oversimplified view of this procedure and do not realize the basic principles involved. Similarly, most investigators do not realize the limitations and degree of effort required to initiate and maintain tree-ring research. Conversely, most scientific investigators do not realize the breadth and depth of what can be accomplished with dendrochronology, given appropriate application of principles and available resources. Therefore, a review of basic principles and concepts is appropriate to this study.

Selection of appropriate tree species

Certain species are now recognized as the best for tree-ring research, partly because of the formation of distinctive, recognizable annual rings and partly because of their common occurrence in the variable climatic regimes and sensitive growth sites that are of interest. Evergreen species, essentially all of the pine, fir, and juniper groups, are the best examples. Although, some juniper species present additional problems resulting from highly variable stem form. Angiosperm groups such as the numerous oak and other species have been used also (cf. Fritts 1976; Schweingruber, Kairiukstis, and Shiyatov 1990). Still other species are useful for more limited or less feasible studies since they have definite annual growth patterns but individual rings that are indistinct and hard to measure, or because they tend to grow in less sensitive growth sites. Such species would allow for studies based on tree/stand age but would be more limited in their potential for crossdating and climatic reconstruction.

Riparian species such as the narrowleaf cottonwood (*Populus angustifolia*), important to this project, are generally of the less sensitive type, although they

are often sensitive enough for precipitation and streamflow studies in the semiarid west (Baker 1990). Similar riparian *Populus* species have proved sensitive enough for crossdating in studies of river channel morphology (*Populus deltoides*, Noble 1979), and very useful for temperature reconstruction in the arctic (*Populus balsamifera*, Dunwiddie, and Edwards 1984).

Chronologies have been established for over 130 species worldwide. A number of woody shrubs such as Big Sagebrush have dendrochronological potential that is still being investigated (Bach 1993).

Site selection and tree sensitivity

The comparison of tree specimens from the arid Southwest to those from New England established that trees from arid regions were more influenced by precipitation regimes than those in other areas. Further, widely spaced trees in these regions also are less influenced by canopy density and other aspects of interspecific competition.

However, it is now widely recognized that even usable tree species vary widely in the resolution of their climatic signal. Trees in the center of a mountain-front zone to which the species is adapted tend to have a much lower sensitivity than trees on the lower forest border for that species. Stands along the lower border will be more limited by moisture stress; conversely, individual trees along the upper limits for the species may be more limited by temperature (e.g., average daily temperature and length of frost-free growing season) than by moisture, even in semiarid settings.

Specific microtopography and other features can have a dramatic effect on tree growth within these overall parameters. Trees growing along the slopes of a rocky ridge with shallow, rapidly drained soils will be much more sensitive to annual rainfall than trees on a valley floor. North slope and south slope stands will show markedly different growth rates as might be expected. Trees growing along even a dry watercourse in Arizona or Wyoming may tap into a seasonal underground water table regime and alleviate a sufficient degree of moisture stress that make them totally unsuitable for crossdating and climatic reconstruction.

Tree-ring investigators now use refined recognition of the factors affecting tree growth to select sites most suited to the study at hand. Although most trees in semiarid regions will be reasonably sensitive to climatic change and therefore useful for climatic reconstruction, specific elevation gradients and microtopography can be used to select stands with the strongest climatic signal. (Care must be taken not to select trees so stressed that they have unusually narrow and erratic ring structures, commonly missing ring segments, or other problems).

Of course, stands can be selected for reasons other than climatic reconstruction. For example, the less sensitive trees around a seasonally active spring

may be best to use if groundwater storage is the topic at hand. The Snake River riparian zone study sites are an example of this type of selective site context. As shown below, even these high altitude, floodplain trees retained sufficient variability in growth patterns for comparative study.

Tree-ring width response signal

Cook (1992) has characterized the "signal" in treerings, i.e., the cause of variation in ring width, as a "linear aggregate model." His conceptual model is very useful and succinct. A modified version could be stated as follows:

$$R_t = A_t + C_t + \delta D1_t + \delta D2_t + S_t + E_t \tag{1}$$

where

t = a given time interval

R_t = the observed ring-width series

A_t = the age-size-related trend in ring width

C_t = the climatically related environmental signal

$D1_t$ = the disturbance pulse caused by a local endogenous disturbance

$D2_t$ = the disturbance pulse caused by a standwide exogenous disturbance

δ = a "binary marker" of the presence (δ = 1) or absence (δ = 1) of each class of disturbance at some time (t)

S_t = soil type, depth, and other geologically related factors

E_t = the largely unexplained year-to-year variability not related to the other signals

Some of the factors affecting tree growth are complexly interwoven in a nonlinear and/or multivariate manner. However, such factors can be treated as linear in a basic conceptual model, or actually transformed mathematically in a more sophisticated treatment. Whether a basic, focused approach such as is utilized in this report, or a long-term, area-wide, mathematically intense study, the general form of tree-ring research is an attempt at some point to treat each contribution as a discrete process.

Cook notes that A_t, C_t, and E_t are assumed to be continuously present while $D1_t$ and $D2_t$ may or may not occur at a given time (t). The growth component of the equation (A_t), a nonstationary process caused in part by simple tree geometry where rings narrow as tree stem circumference increases in size, is

discussed below. The climate term is an aggregate of precipitation and temperature as they effect soil moisture. Contributing factors may be seen as stationary and stochastic or as quasiperiodic and deterministic, depending on the scale of climatic variation being examined and the preferred theory on climatic change; usually they will have an autoregressive component. More specifically, the disturbance processes modelled by the $D1_t$ and $D2_t$ terms are considered to be "pulses" of increased or decreased growth in a signal because they tend to be transient in nature, a few years or a few decades at most.

The S_t "geological" term was not included in the original Cook model. It could be seen as ameliorating or otherwise modifying the effect of the other terms, especially the aggregate climatic variable, rather than a separate process. However, determining factors such as soil type, depth to bedrock, degree of slope, and other similar factors are so important in determining tree-growth rate that they should be added to the current study where soil depth, etc. is more constant.

The E_t term represents unexplained variance remaining after the other terms are considered. It could be seen as an "error term," actual measurement error or errors in the sense of failing to account for specific microtopographic effects (Cook in fact incorporates soil type, etc. in this last term).

Growth forms and standardization of measurements

Because trees have several variations in growth type that affect individual width measurements, many types of dendrochronological analyses require the calculation of standardized measurements called tree-ring indices. As can be seen in some raw-measurements graphs described below, most trees growing in relatively open, undisturbed settings start with a spurt of growth and very wide rings, followed by gradually narrowing rings. This decreasing ring width can be noticed within 10 or 20 years in some dry-site growth forms, but may take 50 to 100 years or more on other trees. In some wet sites such as riparian zones, the age effect may not occur or at least may not be notable until near the very end of a tree's lifespan.

The growth curve in general is due to two factors:

a. Stem geometry, the fact that larger volumes of cell growth may still result in a narrow ring when placed around the circumference of a larger circle (i.e., a horizontal segment of the trunk).

b. A shift in food storage balance from growth of new structure to maintenance of existing structure, as well as other factors in mature trees.

Without removal of the growth factor, it cannot be established that a relatively small ring width near the outer circumference of the trunk is actually relatively wide, signifying a wet period and, thus, is equivalent to a very much wider ring near the center of the tree. In most instances, fitting a similar

curvilinear, exponential trend line or growth curve to the sequence of measurements can be used to correct for this age effect. In some instances (e.g., when there are endogenous or exogenous disturbance pulses in the signal), a more complex polynomial curve is needed. However, complex age-based growth rates and episodes of climatic fluctuation have very similar forms in terms of fluctuation in ring width, and the relationship between the two types of "pulses" can be complex.

The most basic form of standardization involves dividing the actual ring widths by the expected value produced when the growth curve is fitted to the data. This operation produces standardized indices that represent percentage departures from a mean-value function:

$$I_t = \frac{R_t}{G_t} \tag{2}$$

where

I_t = the standardized ring-width index number

R_t = the measured ring width

G_t = the value provided by the expected growth curve

This process transforms the nonstationary ring widths into a new series of stationary indices that have a mean of 1.0 and a relatively constant variance. Logarithmic transformations and other techniques may be more appropriate under some conditions than the simple division model. It is mathematically more correct to average indices than actual widths to produce master chronology (see below).

The actual growth curve used can be selected *a priori* by using inspection of ring-width graphs to fit a typical deterministic curve type (e.g., the exponential curve), or the investigator can use low-pass digital filtering or other stochastic models to fit the most appropriate standardization technique *a posteriori*. Each type of model has disadvantages and advantages. If climatic reconstruction is the goal, deterministic and stochastic models are specific applications of the general model that the fitted function should allow removal of both general tree-age effects and trends from exogenous and endogenous disturbance (Cook et al. 1992):

$$G_t = f\,(A_t,\ \delta D1_t,\ \delta D2_t) \tag{3}$$

However, again using a complex curve to standardize pulses in growth on any particular scale, whether the curve responds to 20-year or 100-year pulses, will smooth out of existence both endogenous canopy release pulses and exogenous climatic cycles of that scale.

Climatic response and crossdating

As early as 1901, A. E. Douglass recognized that the "sequence of favorable and unfavorable climate (wet and dry or warm and cold years) is faithfully recorded by the sequence of wide and narrow rings in large numbers of trees" (Fritts 1976). Douglass was able to establish centuries-long sequences and to crossdate specimens of unknown age, e.g., first stumps from early historic logging and, ultimately, prehistoric specimens more than 2,000 years old.

Crossdating thus depends on the relatively unique sequence of droughts and wet periods that characterize any particular set of years. However, recognition of a sufficiently unique sequence takes a minimum number of rings, never less than 20 to 40, and preferably 50 to 100 or more years.

With an appropriate master sequence established, common climatic signals can be easily recognized in trees up to 40 or 50 km apart. The main climatic pattern (e.g., region-wide droughts) can be recognized in trees up to several hundred km apart, and comparative studies are then still possible. Only the strongest patterns are comparable at distances on a subcontinental scale, but large-scale climatic reconstruction across an entire continent or hemisphere is possible given recording and analysis of enough stations (cf. Fritts 1991a).

Master ring-width chronologies

With careful work, a shared climatic signal (C_t) that allows crossdating is established. Indeed climatic reconstruction is almost an unavoidable aspect of most studies. (As noted above, $D2_t$ is also a shared signal that is difficult to partition from the climatic response.) However, tree-growth patterns retain enough "unshared variance" ($D1_t$ and E_t) that estimates of climatic change, studies of growth rates, or research of any other type is best done by averaging measurements from a large number of trees. As a general rule of thumb, 20 to 40 trees, 2 radii from each, is sufficient to minimize idiosyncratic variation.

Variation in ring widths in individual trees might reflect a number of factors, e.g., unobservable differences in depth to bedrock, a more highly fractured bedrock zone which stores more root water, competitive factors such as changes in canopy structure including, in older rings, inexistent factors from when the tree was a seedling, or an earlier minor, but definite, attack by insects.

Also, trees tend to incorporate changes in width around the circumference of a single ring depending on such factors as degree and direction of slope, stem lean, placement of individual branches and, apparently, just relatively unpredictable lobate growth spurts within a generally roundish trunk. (However, "lobate" growth is no longer thought to be as random as it was once.) (cf. Doyle 1987).

Growth conditioning factors can be treated to some extent by standardized sampling methods, but the nature of a narrow increment boring is that it gives one a look at only a small zone across a variable trunk. Slabs are preferable in all instances since anomalies can be identified, and more individual radii can be measured; but obtaining slabs is seldom as feasible as extracting increment cores.

As might be expected, a number of alternative routes exist for calculating the mean value function that summarizes a master tree-ring sequence. A simple arithmetic mean can be refined by using biweight robust means when extreme outlier values are seen, or autoregressive moving average models can be used to estimate the common signal (cf. Cook, Shiyatov, and Mazepa 1992).

Seasonal response patterns and interspecies comparisons

Tree-ring researchers such as Fritts were able to use recent, detailed meteorological data and concomitant ring widths to establish a much more precise statement of the relationship between tree growth and climatic variation. One principle that emerged was that growth relates very strongly to nutrient stores from the previous growing season, stored food being what a tree uses to initiate and maintain much of the growth during the current warm season. The strongest basic correlations between ring width and variables such as total precipitation tend to be with precipitation for the previous 14 months, for example, rather than with the rainfall from the 3 or 4 months of the current growing season. Failure to realize that there is a built-in, one-year "lag effect" is one of the most common misconceptions about the utility of tree-ring measurements.

Imbedded within the overall lag response pattern are a variety of seasonal response patterns. It has been determined that different tree species vary in sensitivity to moisture and temperature during different seasons. Given a stressed growth site, Great Basin bristlecone pine (*Pinus longaeva*) width sequences incorporate climatic information at about 25 percent each from the previous summer, autumn, and winter. Limber pine (*Pinus flexilis*) has almost (32 percent) of its growth rate determined by the temperature/moisture balance of the preceding autumn, while Ponderosa pine (*Pinus ponderosa*) shows the strongest response to both autumn and spring climate.

Once again, all of these refinements and constraints should be considered before extending the results of the current study.

Climatic calibration, retrodiction, and prediction

With a master chronology established and seasonal response patterns calibrated to recent weather data, interspecific comparison can be used to retrodict detailed past climates on both chronological and spatial scales. This includes

detailed seasonal climatic sequences, streamflow volumes, and other time series to eras as far back as ring sequences exist. Fritts and others familiar with meteorological factors have gone so far as to develop worldwide models of pressure and temperature changes of the large air masses controlling seasonal weather patterns.

Calibration and retrodiction are far beyond the needed scope of this discussion, although such procedures indicate some of the potential for the Snake River dendrochronological data sets.

Dendrochronology in Wyoming

The Department of Anthropology, Dendrochronology Laboratory is housed within departmental archaeology labs. The Dendrochronology Lab operates on a sporadic basis as the need to date archaeological specimens arises, e.g., when student interest or graduate research needs converge, or when Federal or state agencies and other organizations request a specific project. Other tree-ring investigations and some equipment are housed at the Department of Geography and Recreation and the Botany Department; another department involved in tree-ring related research, is the Department of Range Science. Increasing coordination of all these departments' efforts should be a future goal.

Department of Anthropology resources include field equipment and other materials and a basic lab setup which includes a microscope and computerized optical rotary encoder measuring table, as well as relevant software for measuring, graphing, and analyzing measurement data. A small library of relevant references, reports, and data has been gathered through the years. Storage facilities containing a large number of slab-based samples (about 200 slabs or slab segments) and a similar number of increment cores are also part of the facility. Computer manuals based on the current system and adaptations of other available software were also produced as part of current research efforts (Reher, Reher, and Rich 1993; Reher 1993).

Research projects undertaken by the UW Dendrochronology Lab have included projects as diverse as crossdating varied sediments with tree-ring sequences to aid with dating archaeological components at Buffalo Jump in the Black Hills (Reher and Frison 1980), or dendrochronological dating of a number of high altitude Shoshone bighorn sheep traps in the Absaroka Mountains (Frison, Reher, and Walker 1990; Darlington 1984). Other projects have included the feasibility study of streamflow reconstruction for the State Attorney General (Reher 1978) and the dating of an Absaroka Range tipi-like conical pole lodge for the Bureau of Land Management so that it could be salvaged and restored in a local museum.

Many of the UW Dendrochronology Lab projects start during seminars when students are encouraged to take on specimens already on hand and perhaps partially analyzed. Such projects have included general climatic

reconstruction in the Laramie Range (Eakin 1985) or preliminary analysis of the dating potential of late prehistoric/protohistoric Native American warlodges (Cartwright 1985) or trees used for the manufacture of bows (Wood 1985). Recent projects of this type include attempts to date early historic logging episodes (Peterson 1993, Moeller 1993), examining the potential of High Plains woody shrubs (Bach 1993), or studying rates of groundwater percolation in fractured bedrock (Miller 1993).

Other interdisciplinary studies assisted by the Dendrochronology Lab include studies as diverse as a consideration of tree stand ages for a study to aid U.S. Forest Service timber management policy (Honaker 1993), a study of erosional rates and soil formation on the high plains (Anderton 1989), or a study of the relationship of rangeland management to juniper stand regeneration (Waugh 1986).

Much dendrochronological work in Wyoming has been done by other organizations. Several tree-ring studies have formed the basis of UW theses or dissertations, for example the study of water relations in limber pine ecology by McNaughton (1984) or an early study of Ponderosa pine growth on tree geological formations (States 1968). Graduate research partly based on Wyoming trees includes the wide-ranging University of California study of limber pine ecology by Lepper (1980).

Large-scale climatic reconstruction by the Tucson Tree-Ring Lab has led to a network of tree-ring stations throughout the west, including 18 in Wyoming. It should be noted that the data compiled at these different stations are in a database that is part of climatic reconstruction software (Fritts 1991b), making the tree-ring lab data easily the most accessible and useful of any data from the area. Three of these Wyoming stations are in the Jackson Hole area and may prove useful to any future consideration of the Snake River floodplain data.

A rendition of available tree-ring resources is available in the form of a handout at the UW Dendrochronology Lab. Nearly 60 study sites are listed. These sites represent a range of available information, from the fully published Tucson Tree-Ring Lab stations or UW Dendrochronology Lab data sets to the several sites in a graduate thesis that prove useful but fail to adhere to current research standards by reporting actual measurements or indices and on sites that have only been reconnoitered with a few samples gathered.

Recent Relevant Research

The potential for continued tree-ring research is very high. Once appropriate tree resources are located and samples gathered, prepared, and subjected to basic analysis, a wide variety of topics can be investigated. Subsequent study may focus on a specific topic, as is the case for the Snake River dendrochronology project, but the same basic ring-width measurement is essentially all that is required for the development of any of the other topics.

Several recent studies are of more specific interest for the Snake River floodplain tree stands because of the use of floodplain contexts, the study of the same or similar species, the comparisons between species, and the investigation of competitive effects of canopy density. A few comments on these specific references follow; however, because almost all topics in dendroecology are generally relevant to the current study of tree growth, there is no way to be fully comprehensive.

Climate-hydrological Interrelationships

In one of the more sophisticated approaches to dendrochronology available, Baker (1990) studied the "climatic and hydrologic effects on the regeneration of *Populus angustifolia*" in the riparian zone along the Animas River in southwestern Colorado. Baker found that seedling abundance was clearly controlled by certain combinations of unusually cool and/or wet seasons, but not every period of this type was associated with tree abundance. Baker determined that the less frequent generation of major new sets of tree stands depended on high spring and fall peak-flow discharges.

Both available moisture and stand destruction by floods were factors in the form of the riparian forest along the Animas drainage. Peak floods could remove smaller trees, whole stands, or also open new zones for seedling establishment. Baker (1990) noted that simple peak-discharge data did not account for all variation because of its masking of the specific details of the character of a flood event, local variation in stream morphology and gradient, and variable stand ages. However, Baker (1990) did conclude that "good seedling years occurred about 3 times as often as flood flows sufficient to originate a new stand, suggesting that periodicity of flood flows is the more significant regulator of riparian stand origins (1990)."

In a similar study on the Minnesota River, Noble (1979) also determined that sustained, moderate flow during the growing season is important in the regeneration of riparian stands. Another research project on the Little Missouri River in North Dakota (Everitt 1969) used hundreds of trees to establish in great detail the evolution of floodplain morphology as available deposits accumulated or where cut away. Large areas of woodland destroyed by a catastrophic flood were also recorded.

Whereas the current study is oriented more toward a basic examination of growth rates, such studies are suggestive of the effect of flood control on riparian forests on the Snake River floodplain. U.S. Army Corps of Engineers EIS documents (1990) note that:

> "In contrast to typical meandering streams which are confined within well-defined bank lines, historically the Snake River and Gros Ventre River are highly braided streams with poorly defined bank lines and numerous secondary channels extending over a wide floodplain. The Snake and Gros Ventre

River reaches included in this study have high gradients ..., high resultant velocities even during low flows, and transport high bedloads. Rather than rising in some predictable portion to increased discharge, they tend to spread out and flow through an ever increasing network of secondary side channels, eroding the banks, changing courses suddenly, and reforming the channel bed during a single flood event."

Additional work to verify some of the relationships suggested by Baker and others would require sample sizes several times larger than those available. Copies of aerial photographs of the Snake River floodplain study sites are incorporated herein as figures.

Interspecific and intraspecific competition

Many factors affecting site context on the Snake River study sites are probably manifested at least partly in the extent to which they contribute to interspecific and intraspecific competition. In other words, if flood control, disturbance through grazing, or other factors affect the abundance or timing of tree seedling establishment and also the density of understory maintained, then growth rates of seedlings, juveniles, and mature trees will reflect the accompanying variation in competition for soil nutrients and open sunlight.

Numerous studies in dendroecology are directly or indirectly related to this area of study. A study based primarily in the southeastern U.S. evaluated a large number of previously developed and new measures of inter-tree competition (Doyle 1987). Doyle's findings on how relative sizes of neighboring trees, crown-diameter relationships, crown class, measures of fixed and variable radius growing areas, and numerous other measures were more comprehensive than any aspect of the current dendrochronological study. It was confirmed that effects of competition on annual growth increased during drought years, that competition intensified with greater structural variation and with stand development through time.

Another early study by Van Sickle and Hickman (1959) confirmed similar findings with regard to understory. Increased competition between trees and understory also leads directly to decreasing ring width. Although a highly technical evaluation of inter- and intraspecific competition was not the purpose of this study, these findings do at least suggest ways that the WCFW Research Unit canopy data could be integrated with the results of the dendrochronology project.

Sampling young, evenaged stands

Some of the study sites presented evergreen trees and some clumps of cottonwood that could be characterized as versions of "young, evenaged stands." Such work is common in timber management contexts, but the Snake

River fieldwork revealed that such trees would be an important component of the research because the rings of the evergreens species are the most distinct for measurement purposes, and because they tend to be climatically sensitive and, hence, more easily compared to other individual trees, at least to the extent possible given the moisture balance of the growth site. Cottonwood rings have been used for a variety of purposes; field inspection seemed to indicate that they would be usable in this case, but they were still a bit of an unknown quantity until lab analysis was underway. In at least one case, very young evergreen trees were the only evergreens available, and they tended to make up a significant percentage of available trees at most of the sites.

Accordingly, some of the literature on such trees had practical information on their potential use in dendrochronology. A brief report by Zahner (1988) describes how the youngest rings incorporate the strongest age effect and can be deleted from the measurement series, relying then on still relatively young tree ages by comparing ring widths from trees of the same age, e.g., comparing mean ring widths at 5-year intervals from a tree age of 15 years to about 50 years. In this type of approach, the actual date of rings (i.e., 1955) is less important than the comparison of like-aged trees, although the date is known and can be used as needed. Greater control of the age structure allows for more accurate comparison of growth rates and can lead to a better understanding of the contribution to ring width variability of other factors such as climate and endogenous changes.

In another study, Schuster et al. (1992) compare both older, near-timberline and younger, high plains outlier stands of limber pine by using plots of diameter versus age, average number of rings per centimeter, and number of rings in outer 10 cm. Stand age, structure, disturbance history, and other factors emerged as a result of this approach. Again, each of these studies suggests methodologies that can be adapted for the Snake River project.

3 Methodology

Field Methods

Site and sample selection

The dendrochronology samples used for this study came from four study sites dispersed on either side of about 16 km of the Snake River channel (Figures 1 and 2). More detailed 1:24,000-scale maps showing each study site location are incorporated below as Figures 4 through 6 after citation in individual site descriptions. Copies of aerial photographs supplied by Corps of Engineers project officials show both the general nature of the study area and the specific location of the WCFW Research Unit vegetation transects. Copies of these are included below as Figures 7 through 9.

The four sites had been previously selected and studied by the WCFW Research Unit as a representative sample of several types of floodplain contexts, relative to the presence or absence of flood control levees, and the presence or absence of disturbance such as from levee-breaching floods and grazing. The categories of site context are summarized in Table 1.

More specifically, the actual shape and size of the dendrochronological sample units were determined by the following factors:

a. The location, spacing, length and orientation of the WCFW Research Unit vegetation sampling transects.

b. Location of the number and types of trees suitable for tree-ring dating.

The sample quadrat was essentially the rectangle defined by the length and spacing of the vegetative sampling transect; most trees sampled came from within this quadrat. This area was then extended by various distances to incorporate additional trees as needed to enhance the site sample, e.g., to obtain larger trees or to increase the sample size of a given species. However, the size of the sampling quadrat was restricted to adjacent areas of similar context so that extraneous endogenous and exogenous "noise" would not be introduced into the ring-width sequence. For example, although additional evergreen

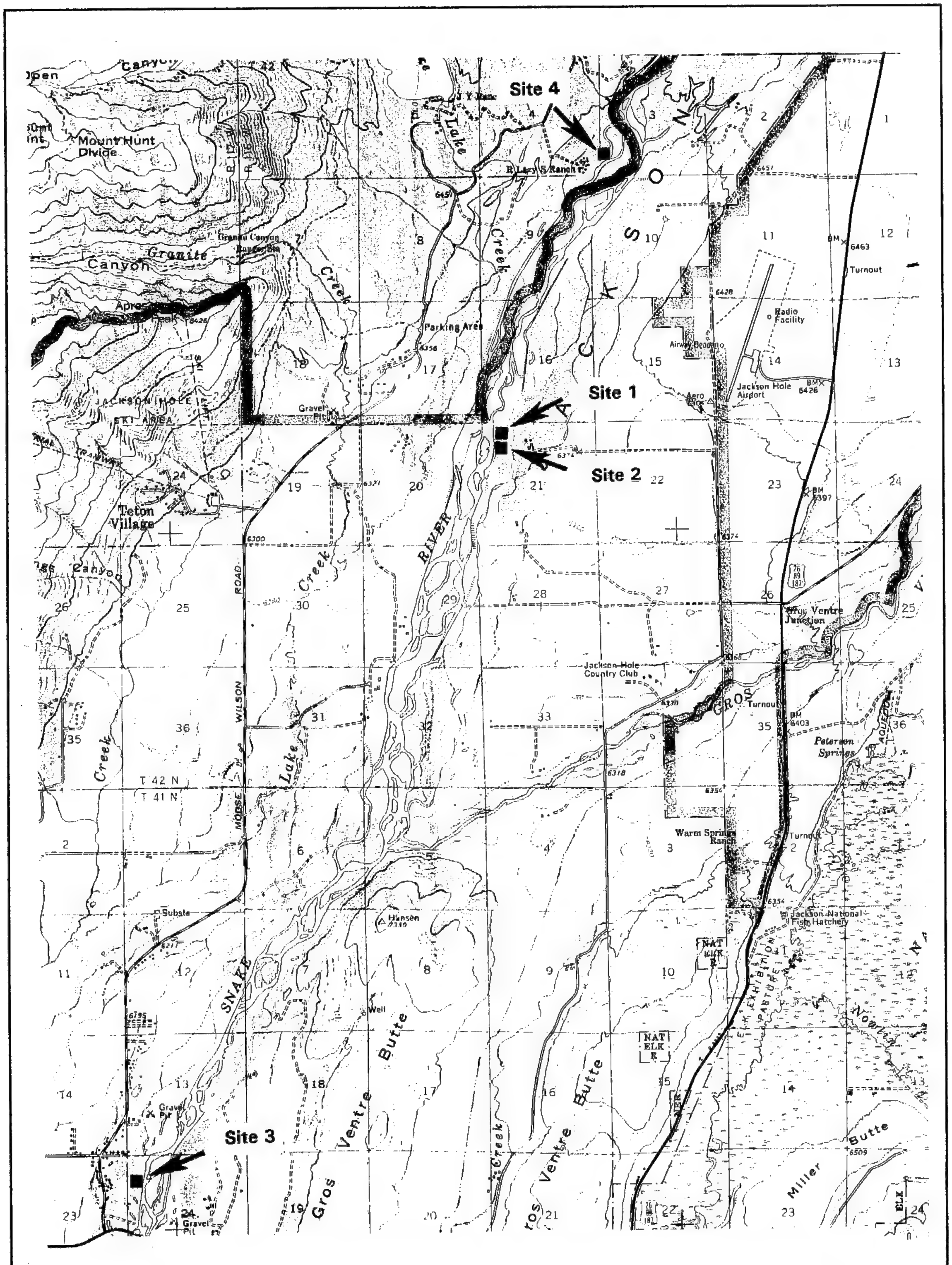


Figure 2. Location of Snake River dendrochronology study areas (Continued)

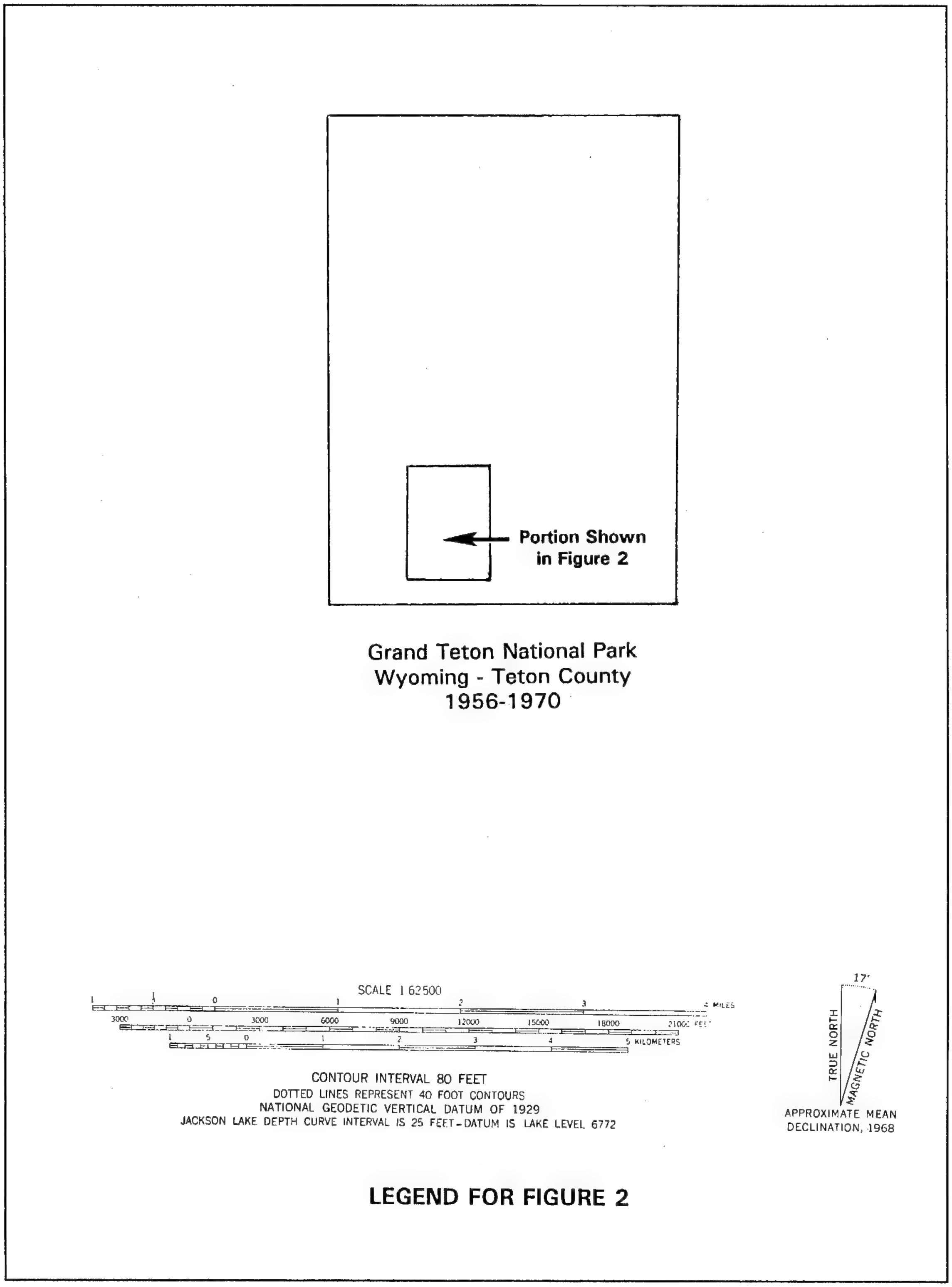


Figure 2. (Concluded)

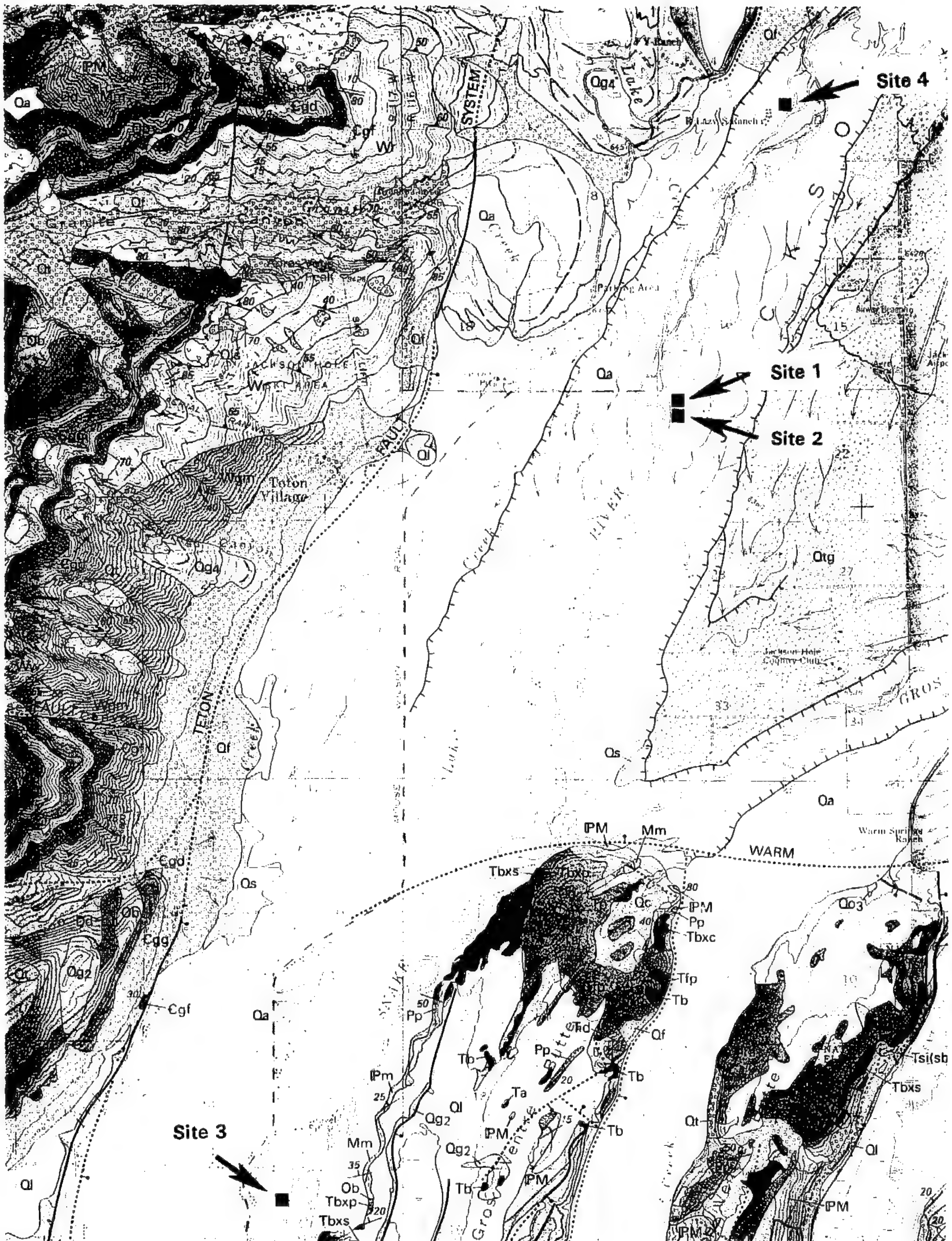
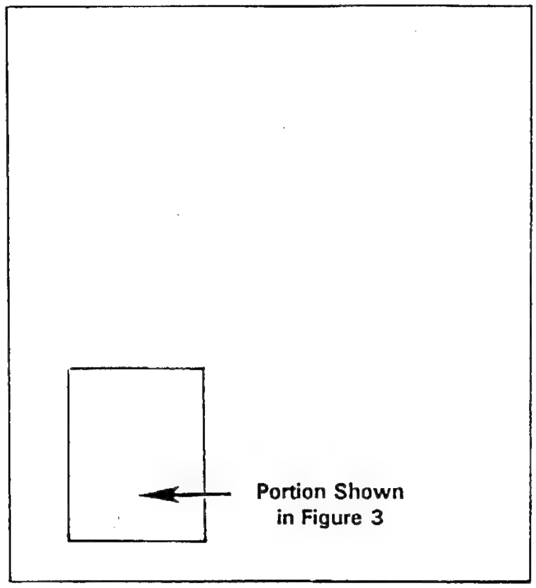
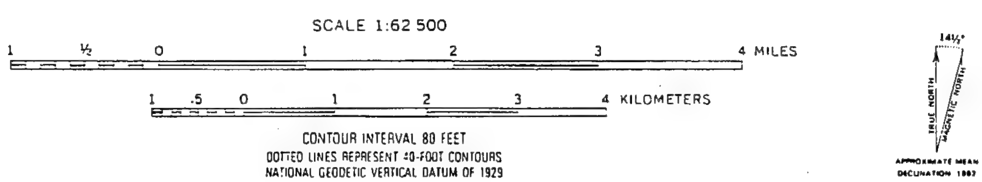


Figure 3. Geology of Snake River dendrochronology study areas (Sheet 1 of 3)



Geologic Map of Grand Teton National Park, Teton County, Wyoming

J.D. Love, John C. Reed, Jr., and Ann Coe Christiansen
1992



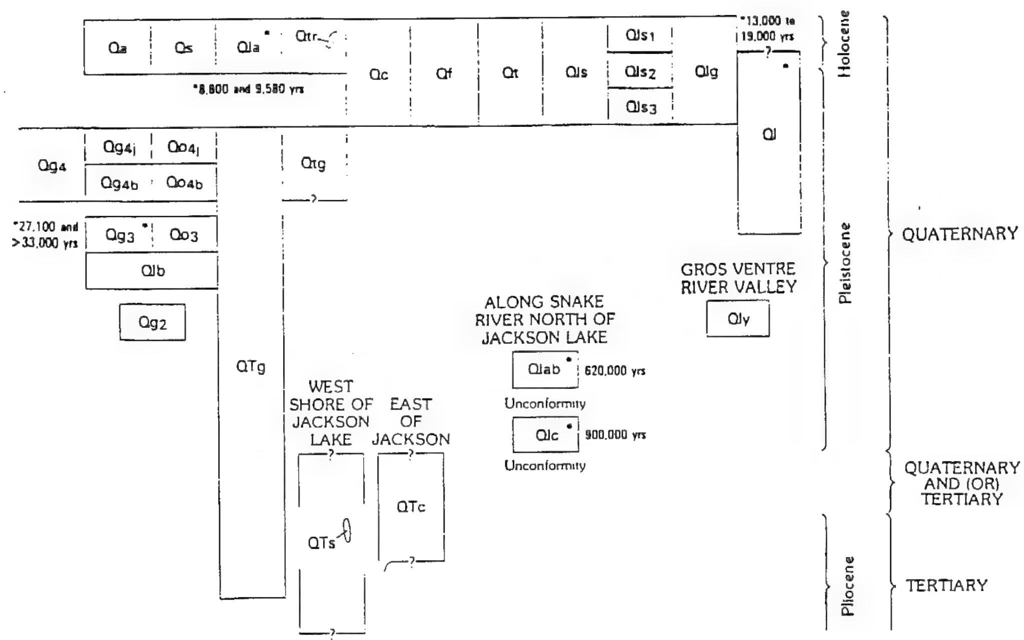
LEGEND FOR FIGURE 3

Figure 3. (Sheet 2 of 3)

DESCRIPTION OF MAP UNITS

[Asterisk in box shows dated unit: ^{14}C and K-Ar ages shown in table 1]

QUATERNARY AND (OR) TERTIARY DEPOSITS



Holocene sedimentary rocks

Qa **Alluvium, gravel and sand, and flood-plain deposits**

Alluvium—Gravel, sand, silt, and clay along modern streams. In places includes fan, glacial outwash, and stream-laid ice-contact deposits; in some forest-covered areas may include other types of surficial deposits

Gravel and sand—Along and adjacent to active channelways of major streams; composed chiefly of quartzite roundstones

Flood-plain deposits—Sand and gravel overlain by silt and clay in low terraces; in places inundated during modern floods

Qs **Swamp deposits**—Dark-gray and brown clay, silt, and fine sand; rich in debris

Qla **Lacustrine and related deposits**—Thinly laminated white marl, ash, and clay. May have accumulated in kettles

Qtr **Travertine**—Gray limestone deposited by springs

Holocene and Pleistocene sedimentary deposits

Qc **Colluvium**—Silt to boulder-sized rocks derived from underlying and adjacent units. Locally includes glacial drift

Qf **Alluvial-fan deposits**—Crudely stratified deposits of boulders, gravel, sand, silt, and clay, generally coarse at the apex and fine at distal margins. Commonly gradational into talus in mountain areas. Along Spread Creek includes fan deposits composed of white ash, silt, clay, and sand derived largely from Colter (Tc) and Teewinot (Tte) Formations

Qt **Talus and related deposits**—Coarse angular poorly sorted rock debris in talus slopes, talus fans, rock glaciers, and moraines of Holocene glaciers

Qls **Landslide debris**—Chaotically mixed boulders and finer rock debris

Qls_1 **Unit 1 (Holocene)**—Still moving locally

ADDITIONAL LEGEND FOR FIGURE 3

Figure 3. (Sheet 3 of 3)

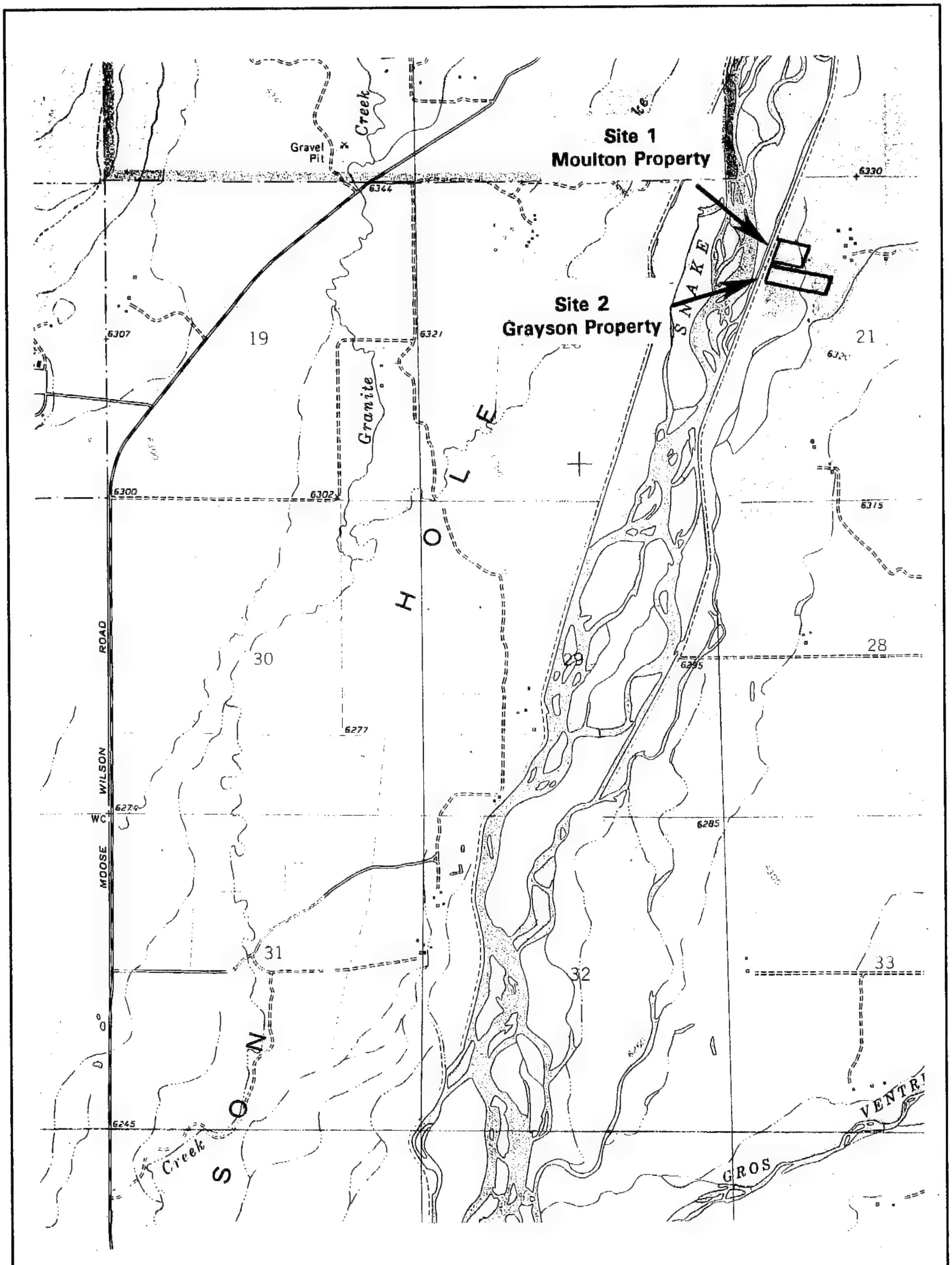
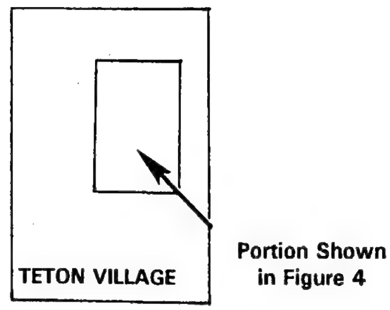
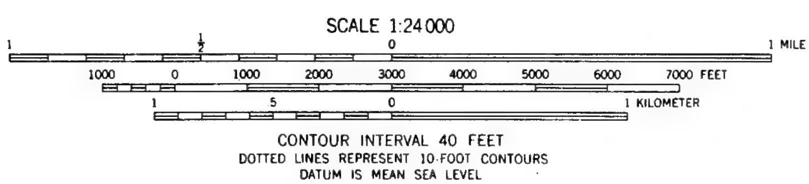
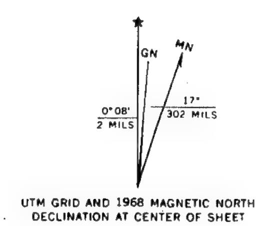


Figure 4. Specific locations of Site 1 and Site 2 study areas (Continued)



TETON VILLAGE, WYO.
N4330—W11045/7.5
1968





LEGEND FOR FIGURE 4

Figure 4. (Concluded)

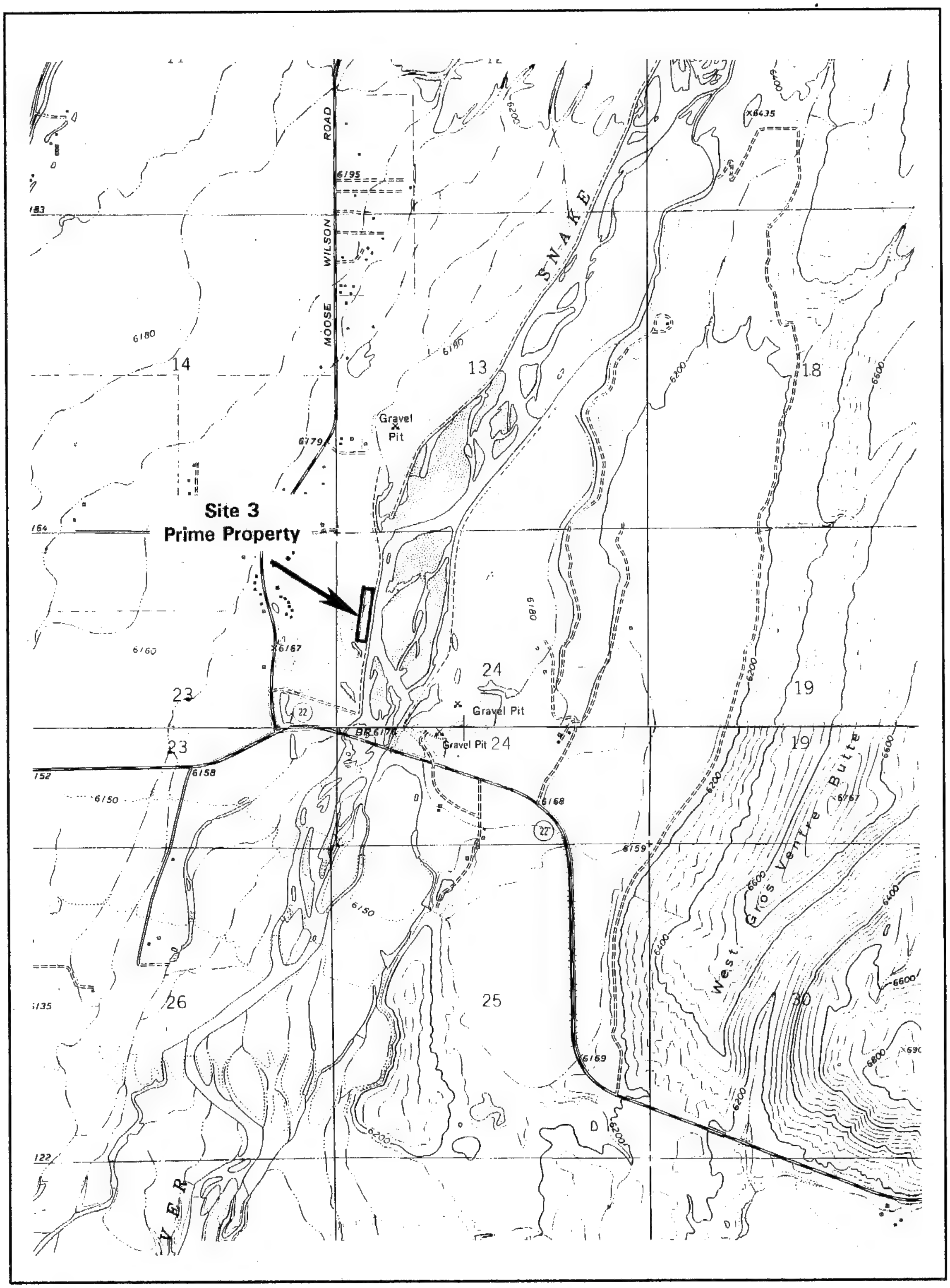


Figure 5. Specific location of Site 3 study area (Continued)

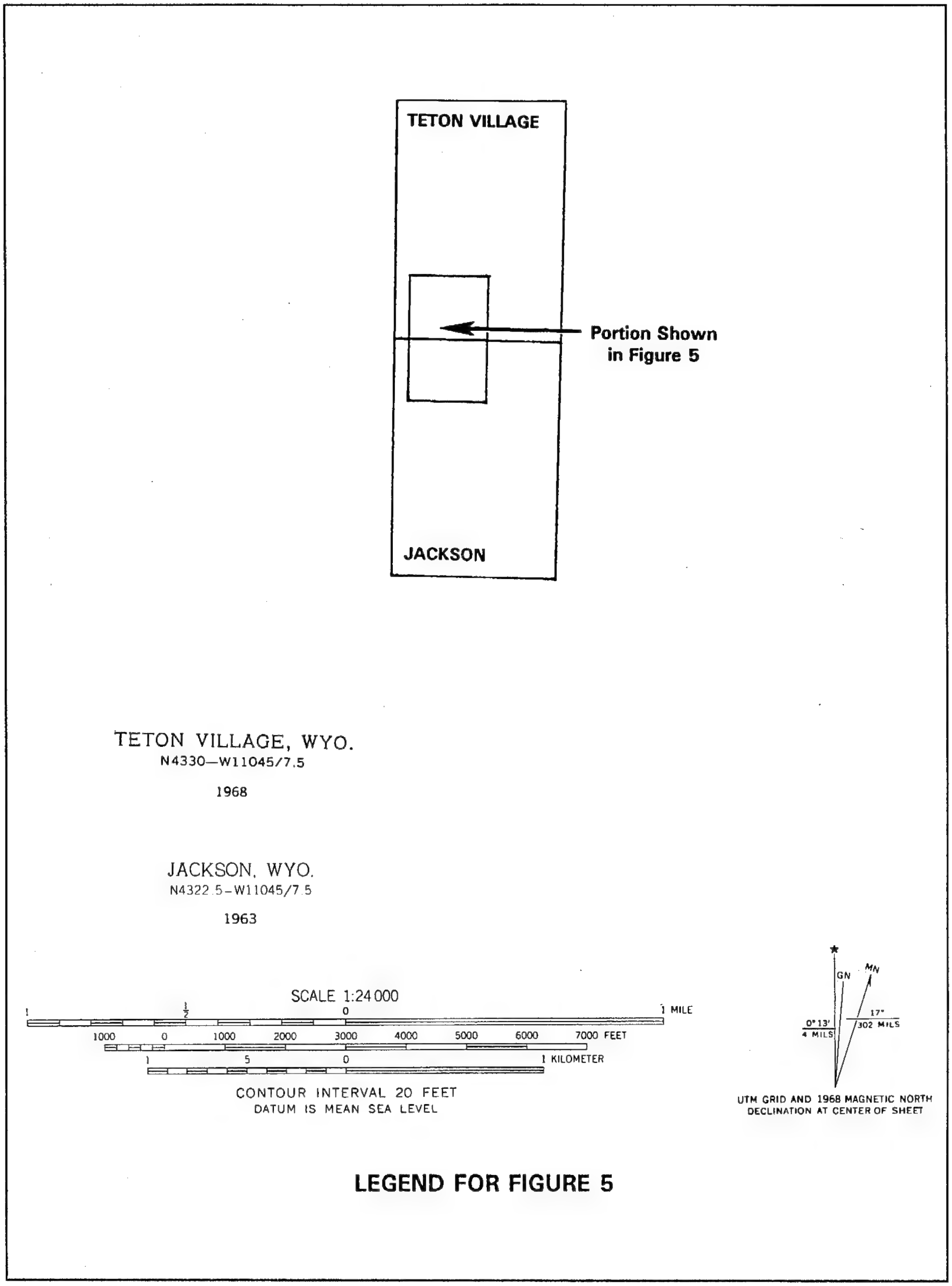


Figure 5. (Concluded)

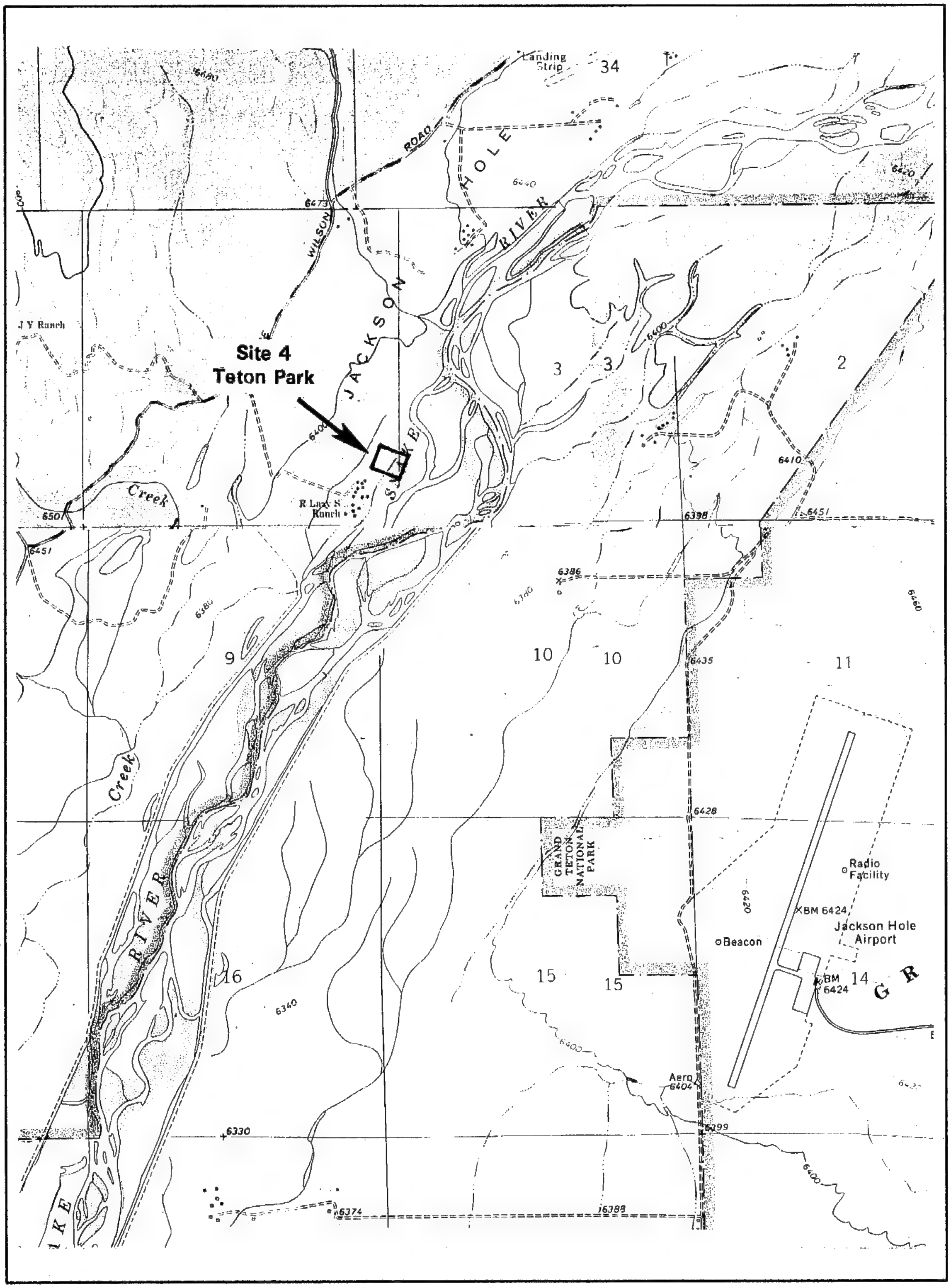
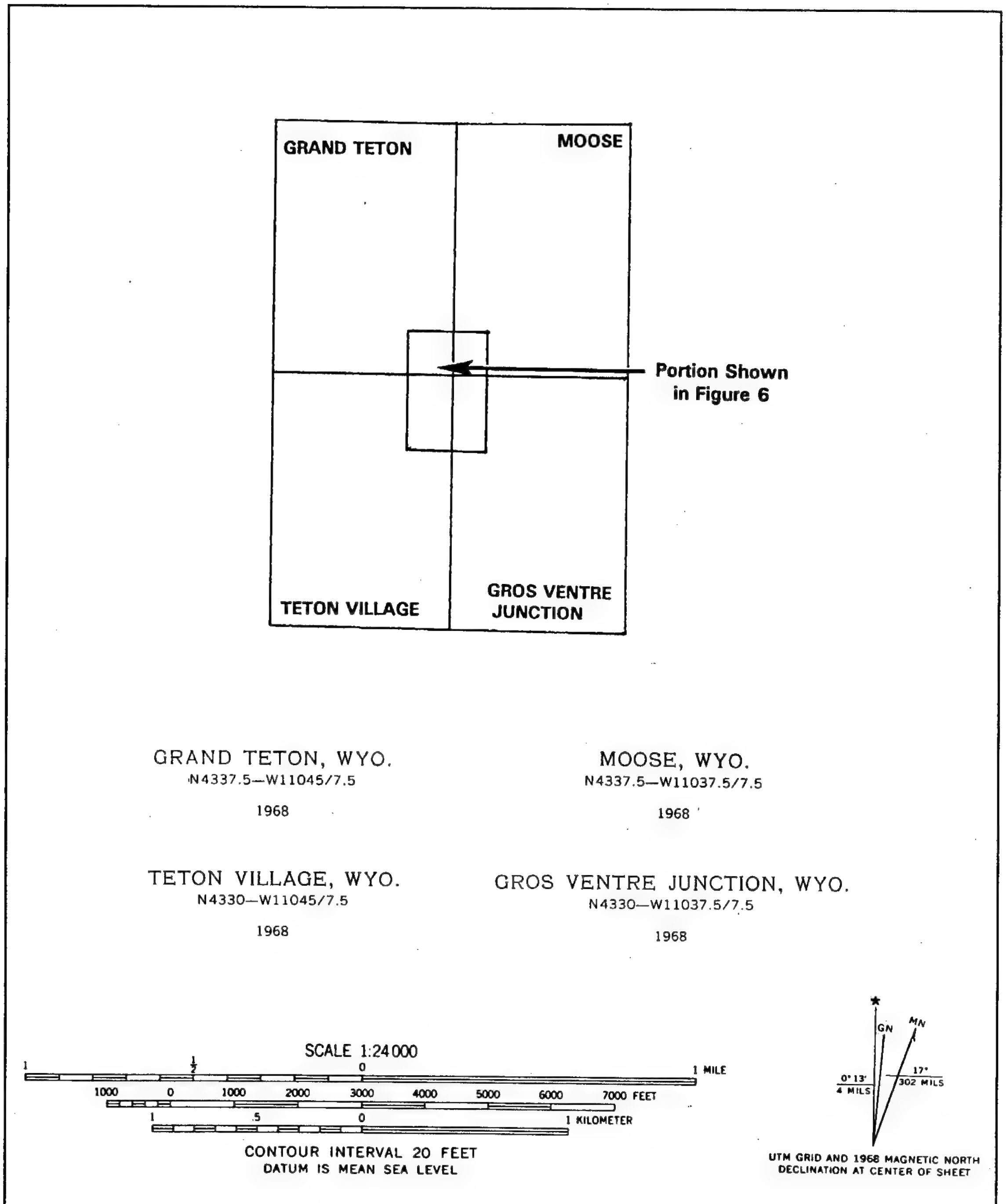


Figure 6. Specific location of Site 4 study area (Continued)



LEGEND FOR FIGURE 6

Figure 6. (Concluded)

Figure 7. Aerial photograph showing location of vegetation transects 5 through 12 at Sites 1 and 2

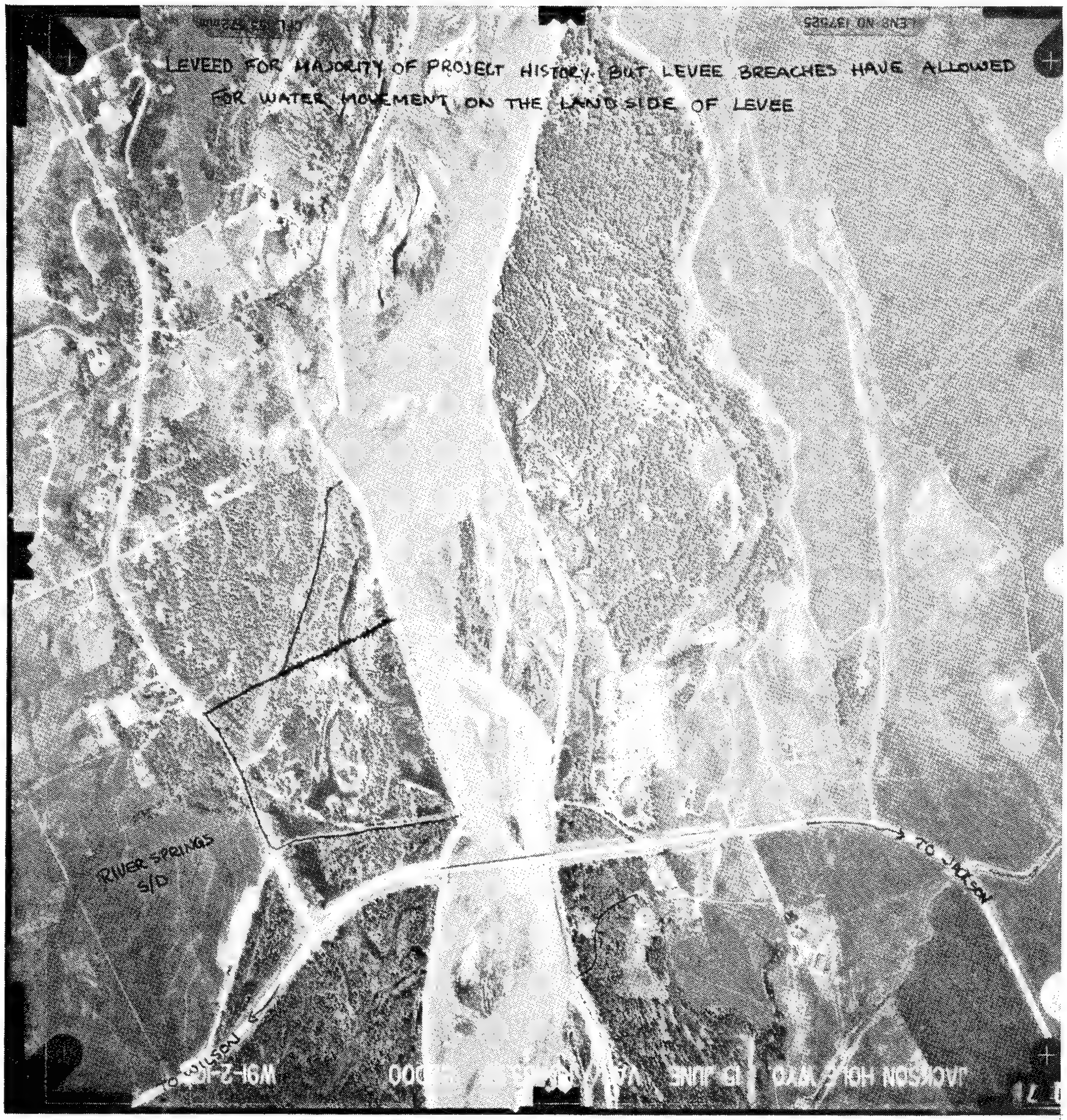


Figure 8. Aerial photograph showing location of vegetation transects 13 through 16 at Site 3

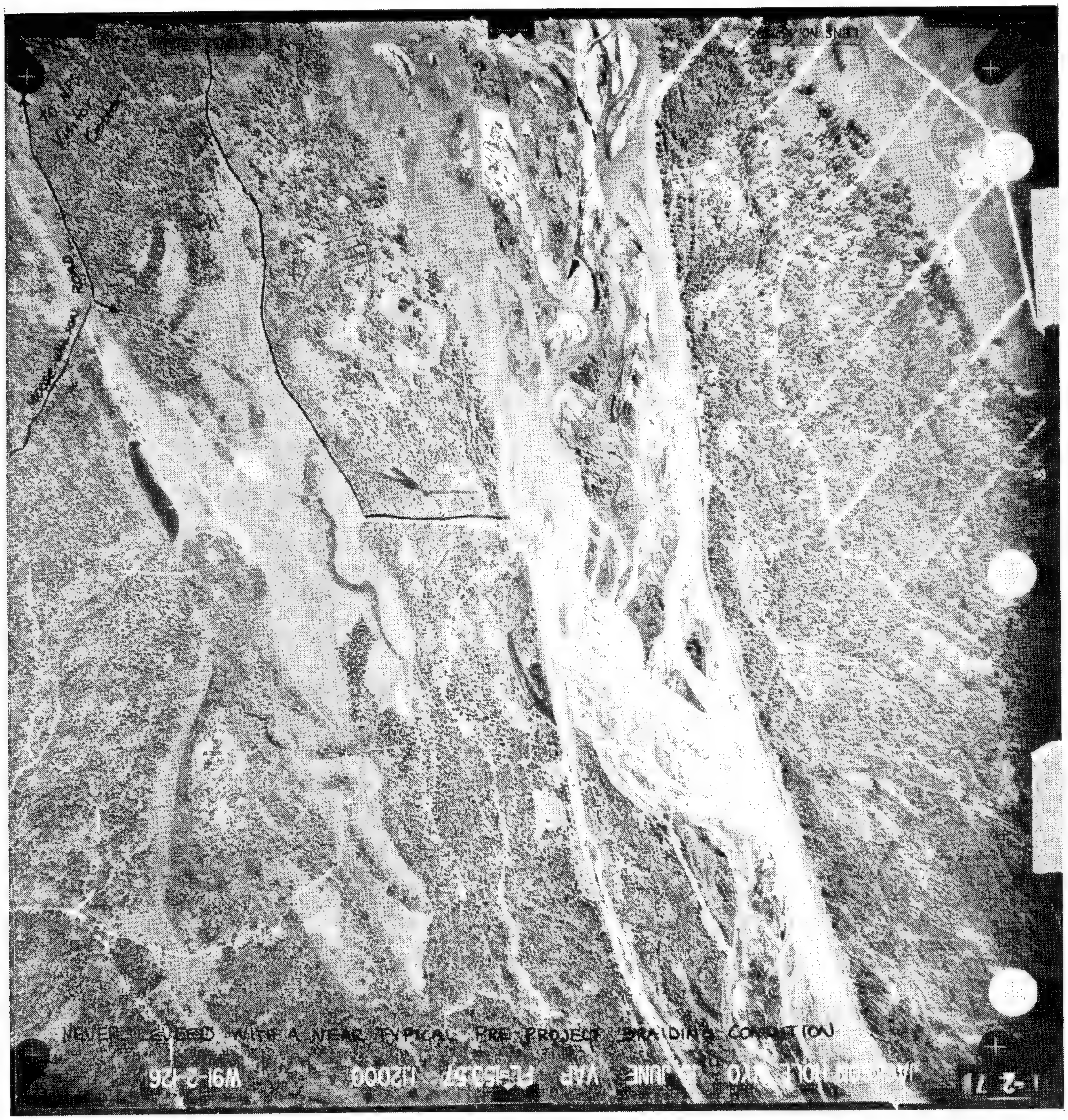


Figure 9. Aerial photograph showing location of vegetation transects 1 through 4 at Site 4

Table 1
Study Sites and Site Context

Site	Context/Condition
Site 1 — Moulton Property	East side of Snake River floodplain behind levee, consistently used for livestock grazing. (Noted on Corps of Engineers aerial photos as "leveed for majority of project history and typical of land management practices of area.")
Site 2 — Grayson Property	East side of Snake River floodplain behind levee, not grazed, undisturbed. (Noted by Corps as "leveed for majority of project but protected.")
Site 3 — Prime Property	West side of Snake River floodplain behind levee roadways, various other disturbances. (Noted by Corps as "leveed for majority of project, but history of levee breaches have allowed for water movement on the land side of levee.")
Site 4 — Grand Teton Park	West side of Snake River adjacent to river channel, no flood control levee, undisturbed. (Noted by Corps as "never leveed with a near typical pre-project braided condition.")

samples could have been obtained, the study did not cross a large meander scar pond at Site 1 to sample yet another 100 or 200 m farther back from the river channel.

The sample areas thus can be defined by a rectangle extending roughly perpendicularly back from one edge of the nearest Snake River channel (either the landward side of a levee base or the current cutbank in the case of Teton Park, Site 4). Quadrats tended to be about 50 to 200 m along a side.

Trees were selected on a judgmental basis until appropriate numbers had been cored. Trees selected came from four main species: two evergreen species and two cottonwood species (see below). Other tree species (e.g., quaking aspen, *Populus tremuloides*) present in some of the study areas and large shrub species were not sampled. Cottonwoods selected tended to be from the larger sapling class/small mature class (8- to 10-in.[1] diameter breast height (dbh)) up to the largest cottonwoods available (about 30-in. dbh).

Cottonwoods were the most prolific species, and numerous trees of appropriate size were available so, sampling efforts gradually converged on a strategy which consisted of:

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1 A table of factors for converting non-SI units of measurement to SI units is presented on page xi.

a. Selection of trees dispersed across the sampling site, both close to and also at the maximum distance from the river.

b. Selection of two or three trees from individual clusters so that patterns of very localized, endogenous responses would be more consistently represented.

c. Selection of some of the larger trees at the site to maximize time span of the ring sequences available.

d. Selection of an adequate minimum number of cottonwoods at each site, e.g., about 5 to 10 trees usually with more than one core each.

e. Selection of a sample of black cottonwood when it occurred commonly (Site 1) so that growth trends could be compared to the more common narrowleaf cottonwood.

Several of the states numbered very few evergreens, or only one of the two species (lodgepole pine and subalpine fir) might occur. Consequently, most were cored whenever they were encountered. This gave a definite representation from sapling size (< 226 mm), along with a few larger trees. The sampling strategy might be described as below:

a. Selection of trees across the sampling site, including ones very close to and also at the maximum distance from the river, whenever adequate dispersion was encountered.

b. Selection of the largest trees available to maximize core length.

c. Selection of most, if not all, evergreens in a site area to maximize sample size for each evergreen species, and extraction of more than one radii from each tree.

Crucial to this study was the fact that the four study sites were very comparable with regard to many of the major variables affecting tree growth. Macroclimate (seasonal temperature and precipitation balance), and microclimate (e.g., slope, aspect, and other factors) could be expected to be essentially held constant for the study sites (the C_t term in the linear aggregate model). As the above review of the literature implies, methodologies exist for basic control of differences in tree stand age structure (A_t). Geology and soils (S_t) were generally comparable. Thus, differences in ring width, as translated into growth rates, should result from minor differences in interspecific competition and other factors largely attributable to cumulative affects ($\delta D2_t$) from the construction of flood control levees or other human intervention ($\delta D1_t$), plus unknown factors (E_t).

Site descriptions

All sites are well out into the floodplain, with the underlying geology consisting entirely of coarse reworked alluvium at elevations ranging between about 6,150 and 6,380 ft above sea level. The Teton National Park Geology Map characterizes this portion of the floodplain as:

> "Qa — Quaternary alluvium: Gravel, sand, silt, and clay . . . in places includes fan, glacial outwash, and stream-laid ice contact deposits . . . Gravel and Sand: along and adjacent to channelways of major streams; composed chiefly of quartzite roundstones . . . Flood-plain Deposits: sand and gravel overlain by silt and clay in low terraces; in places inundated during modern floods" (see Figure 3 and accompanying legends; Love, Reed, and Christiansen 1992).

The coarse cobble bars that make up most of the underlying deposits are buried versions of the complex, braided channels and cobble, gravel, and sand bars that make up the current river drainage. This coarse alluvium allows free percolation of water and a consistently high water table. All of the sites had some expression of surface water in low spots in the floodplain even during field work in the low-water period in September, either small pools or small stretches of intermittent, slowly flowing water. At the time of field work, the water table appeared to range from about 0.5 to 1 m below the current ground surface.

Numerous small streams and marshes dot the floodplain further back than the "riverside" dendrochronological study areas. Site 3 (see below) is downstream from the confluence of the Snake River and the Gross Ventre River, while the other sites are upstream from this confluence. With all of the ground water movement that characterizes the floodplain as a whole, this fact did not appear to make enough of a difference in ground water to have a definite effect on tree growth.

Site 1—Moulton Property. Site 1, the Moulton Site, is located north of Jackson on the east side of the Snake River (Figures 1, 2, and 4). The study area is adjacent to the Moulton Ranch headquarters and can be characterized as intensely grazed. Although this was not confirmed, use of the area as a winter bed-ground for cattle is likely. There is also incidental grazing by ranch horses and cattle being kept close to the ranch buildings. Damage to trees from rubbing or chewing by animals was noted.

As with the other stations, the sampling station at the Moulton Site was centered on the previously established vegetation transects, then extended out short distances as needed to include a few of the better trees. Our sample quadrat is easily incorporated within a rectangle of 60 m east-west and 150 m north-south. It extended from the road along the backside of the levee and across the floodplain to a small intermittent drainage paralleling the main channel (Figure 4; interior of sample rectangles shown on 1:24,000-scale figures

are approximately to scale; also note aerial photo incorporated as Figure 7 after site descriptions).

Site 1 is characterized by relatively open stands of mature, narrowleaf cottonwood (*Populus angustifloia*), and black cottonwood (*Populus trichocarpa*), with young to mature subalpine fir (*Abies lasiocarpa*). No lodgepole pines (*Pinus contorta*) were found in the sampling zone. Because of a high percentage of mature trees, canopy coverage is the highest of the four sites, while seedlings had a low occurrence. This site had the lowest shrub density but is recorded as having the highest herbaceous ground cover. Dead fall both standing and on the ground is low (Anderson 1993).

Site 2—Grayson Property. Site 2, the Grayson Site, is located directly south of the Moulton Property on the east side of the river (Figures 1, 2, and 4). It has not been grazed; in fact, it apparently has been maintained in a completely undisturbed state for some time. The small stream-like water course seen in Site 1 continues intermittently through this property, and most of the sampled trees lie between the river and this stream channel, or just across and east of the stream. The study site could be incorporated within a rectangle about 200 m east-west by 150 m north-south.

The three types of trees utilized include narrowleaf cottonwood, black cottonwood, and subalpine fir. The difference between Sites 1 and 2 is dramatic, with the Grayson Site having much greater tree density and much more lush understory. However, much of the canopy is expressed as clumps of saplings or mature trees (some very large cottonwoods do occur) or as isolated evergreens; canopy density tends to rank behind the large, overarching trees of Site 1 but ahead of Sites 3 and 4.

Similarly, the percent herbaceous ground cover ranks behind Site 1 (30 versus 46 percent, Anderson 1993). However, though it may be extending beyond the expertise of the dendrochronological crew, it was clear from walking through the ground cover at Site 2 that it tended to have a higher structure (not surprising given the "cropped" effect of grazing on much of Site 1); it is possible that larger, more deeply rooted understory plants may contribute to increased interspecific competition at Site 2. The amount of dead-standing or fallen-woody material is low at this site (Anderson 1993).

Site 3—Prime Property. Site 3, the Prime Property, located on the west side of the Snake River, is the farthest south of the four sites. The tree-ring sampling again started just behind the levee system and extended back into the floodplain a short distance (Figures 1, 2, 5, and 8). Small pools of water occur sporadically in the study area, and larger pools can be found in other floodplain areas nearby, all reflecting low spots in old meander scars. The study area was extended northward from the vegetation transects to allow recovery of slabs from cottonwoods that had been sawed down along the western base of the levee, giving a sampled unit rectangle of about 50 m east-west by 300 m north-south.

Three tree species were examined including narrowleaf cottonwood, subalpine fir, and lodgepole pine. Only a few small evergreens occurred at this site; thus, the evergreen sample tends to be made up of young trees of sapling size. Seedlings were much more common here than at the other sites. The ground cover is low, and the amount of dead-woody material is high (Anderson 1993).

This area is used for recreation purposes including fishing, boating, and possibly camping. Roadways associated with these activities and other types of disturbance of the understory were common; therefore, exposed gravel and lower ground cover gives the visitor a very different impression of this site compared with all of the others.

Site 4—Grand Teton National Park. Site 4, located several miles into the southern end of Grand Teton National Park is the northernmost of the study sites (Figures 1, 2, 6, and 9). This site is on the west side of the Snake River whose course has been left in its natural condition, not leveed. As with most of the other study sites, a small, intermittent water course runs parallel to the river, in this case about 120 m to the west. The vegetation transects in this case did not start at the river's edge but were back on the west side of the small water course. Sampling was configured to overlap this vegetation transect area and then to extend eastward to the riverbank (Figure 6). The sampling zone is incorporated in a rectangle about 200 m east-west by 100 m north-south.

Because of the changeable nature of the edges of the Snake River and the age of available USGS quads, distance estimates do not show the sample quadrat as extending to the river's edge on Figure 6, but it did in fact do so. Active, westward erosion of the bank in this area was, in fact, still visible during fieldwork.

The sampled trees were located adjacent to the river and back across this small watercourse, but mostly between it and the river. Tree types sampled included narrowleaf cottonwood, subalpine fir, and lodgepole pine. Quaking aspen (*Populus tremuloides*) was also common in the area.

Site 4 had a more open appearance with grassy/forbaceous meadows scattered among the tree stands and some broad, open terraces near the river; hence, it was found to have the lowest average canopy coverage. The ground cover was the second highest of the study areas but essentially the same as the Moulton Property (44 versus 46 percent). The site also had the highest shrub diversity and the highest amount of deadfall material (Anderson 1993).

Sample collection

The dendrochronology team from the UW Department of Anthropology extracted cores and slabs from the four sites 5 through 9 September, 1993. After a general reconnaissance of access routes and the sample sites to estimate

time required and the number and type of suitable trees, each study site was revisited and samples were collected.

The start of each vegetation transect had been clearly marked with flagging tape that was removed as the fieldwork was completed. Using these transects for orientation, the study site and all adjacent areas were walked out, and specific individual trees were located. This was especially important with regard to locating all available conifer trees. The fairly large amount of equipment needed for field collection was then gathered and placed in backpacks at the vehicle, and sample collection progressed in a zigzag pattern across the sample area.

Within a short time, an efficient system was developed whereby the field crew converged on the tree selected by the project director, and each team member completed a set of assigned tasks. While two members extracted the actual core with an increment borer, wrapped the cores in aluminum foil to preserve moisture, and labelled and placed them in protective tubes, the other team members photographed the tree and site, and recorded the basic documentation for each tree and the site. As appropriate, one or two increment coring teams were used, and coring could move ahead of recorders to keep a steady rate of work in progress.

Trees were not cored consistently at chest height as is standard for many dendrochronological studies (cf. Schweingruber 1989; Schweingruber, Kairiukstis, and Shiyatov 1990; Gemmill, McBride, and Laven 1982). The Snake River samples tended to be taken from as low a height as possible on the smaller trees to maximize the number of rings/years that could be obtained. Coring at chest height is more common in studies such as climatic reconstruction where it both produces a reasonable methodological standard and excludes some of the earliest rings where the age effect (A_t) most strongly masks the climatic signal (C_t).

It is commonly known that coring at the standard chest height misses the rings from when the tree had not attained this height, as many as 5 to 10 rings, so in other types of studies (e.g., forestry studies of true stand age), the lowest possible coring point is utilized (cf. Baker 1990, Honaker 1994). Also, many of the riparian zone trees, especially the younger trees, still had numerous low branches, and the team wanted to minimize the few that had to be trimmed to turn the increment borer handle.

As is always the case, a combination of visual inspection and experience was used to come as close as possible to the center pith of the tree. In all cases except for the largest cottonwoods, the team was able to core completely through the tree to produce two radii from opposite sides at the same height. Some trees were cored more than once to maximize information and minimize individual variability (cf. Doyle 1987; Schweingruber, Kairiukstis, and Shiyatov 1990). Taking multiple cores to allow for hollow defects in the cottonwoods was also common.

Increment boring tubes were kept lubricated with kerosene, which aids by acting as a solvent for pine pitch. Cores were plugged by using a small hammer to drive a hardwood dowel into the hole after removing the boring. All samples were increment cores with the exception of four slabs, three from cottonwood logs previously cut down along the levee at Site 3, and one small dead branch growing from the base of one of the firs at Site 1. Specimen direction was recorded with a compass, but no constituent side of the tree was used since there was no slope or other relevant reason for doing so.

Basic documentation included a set of forms for each tree, along with sketch maps of sample location, photographs of each tree, and location on the USGS 1:24,000-scale quad. Paced distances and compass bearings were also noted so that the site sketch maps could be verified and refined in the lab. Although very basic with estimated distances, these sketches are a useful rendition of how sampling was aligned (Figures 10 through 13).

In addition to maps and photographs, basic field documentation included the following information:

a. Sample number.

b. Date.

c. Recorder.

d. Tree species.

e. Tree characteristics definitions.

f. Location of site.

g. Elevation and other map-based data.

h. Type of specimen.

i. Specific direction.

j. Tree height.

k. Tree diameter.

l. Core height.

m. Basal circumference.

n. Core circumference.

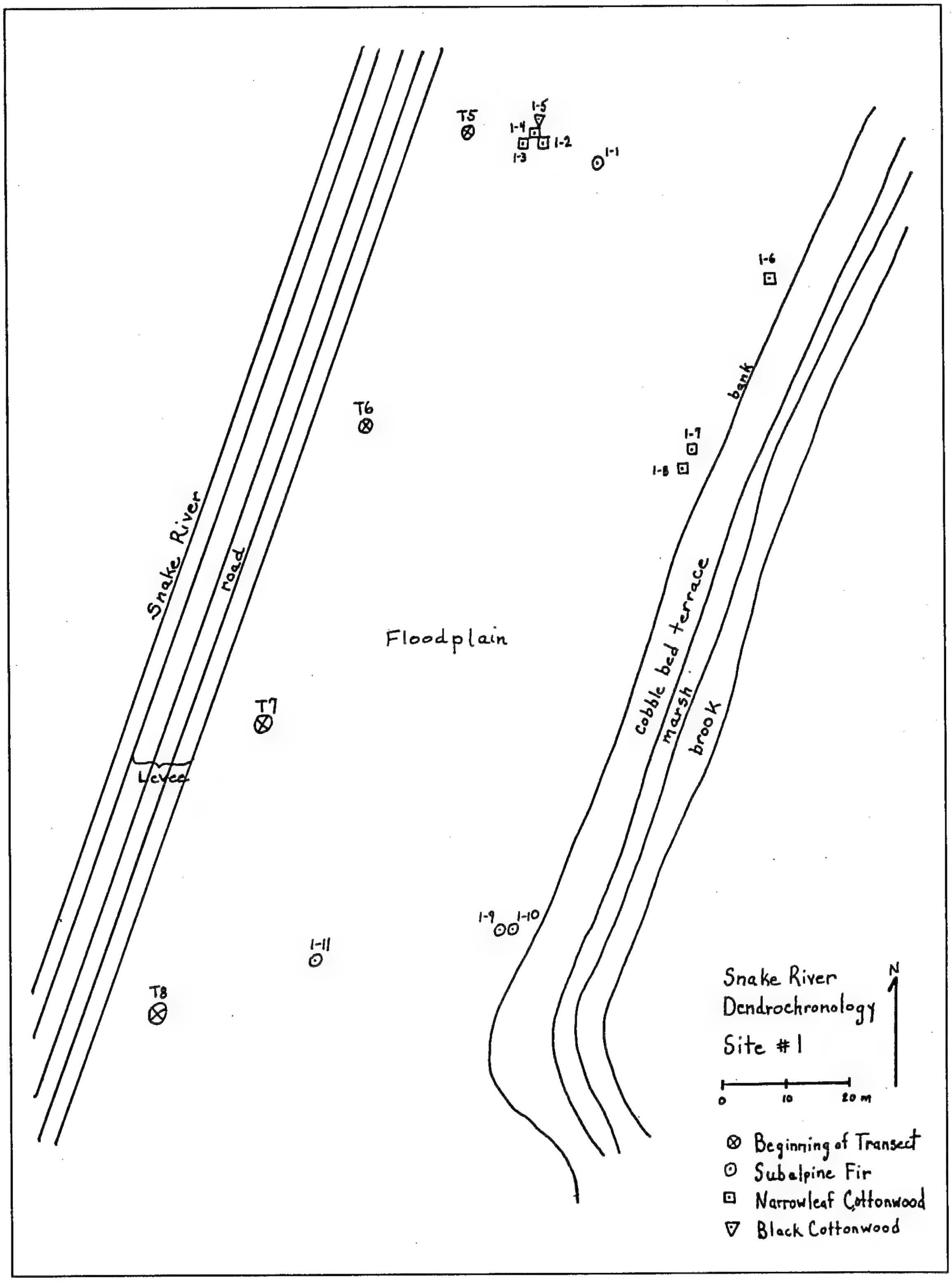

Figure 10. Sketch map showing location of start of vegetation transects 5 through 8, and location of trees sampled at Site 1

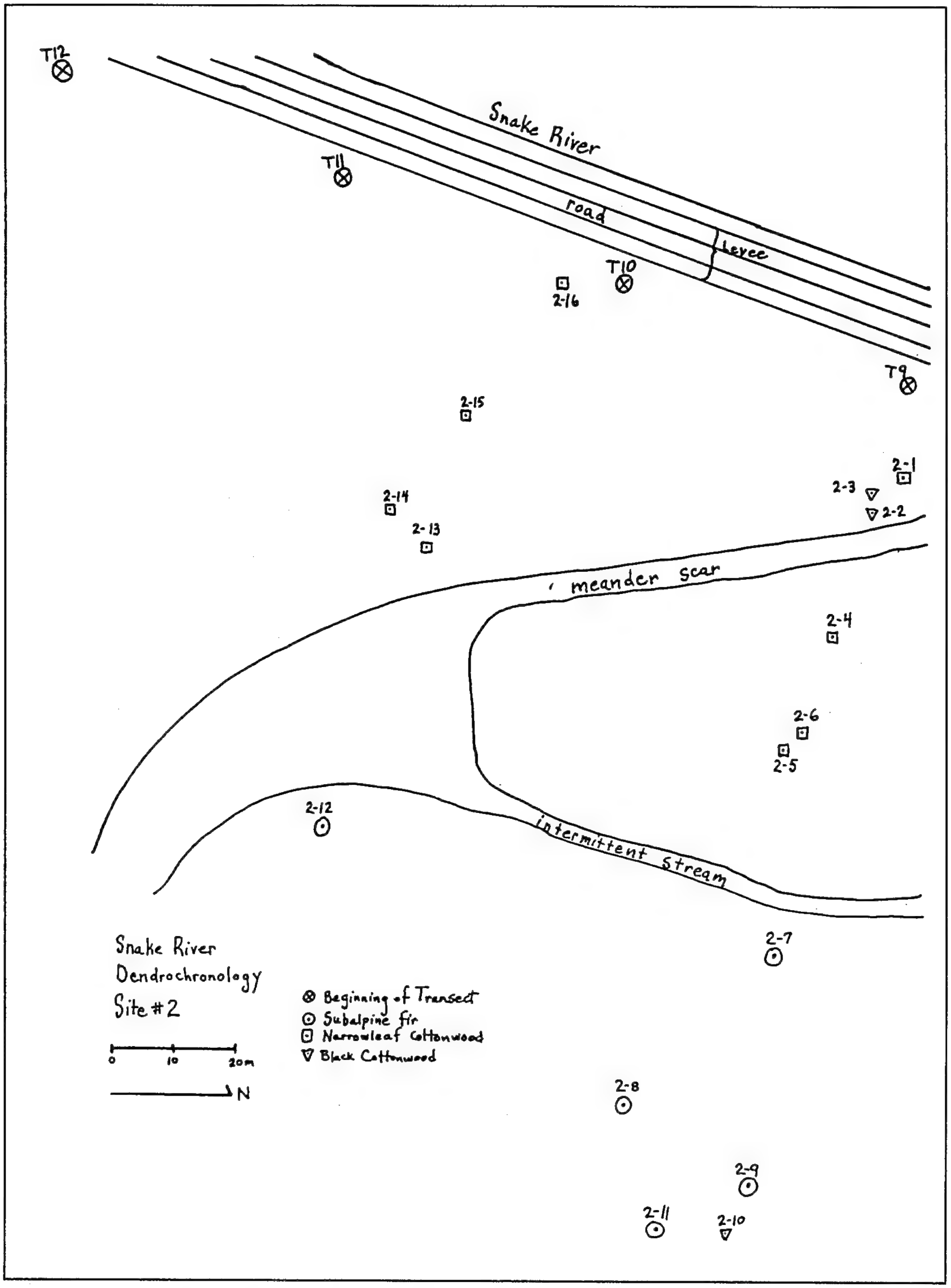

Figure 11. Sketch map showing location of start of vegetation transects 9 through 12 and location of trees sampled at Site 2

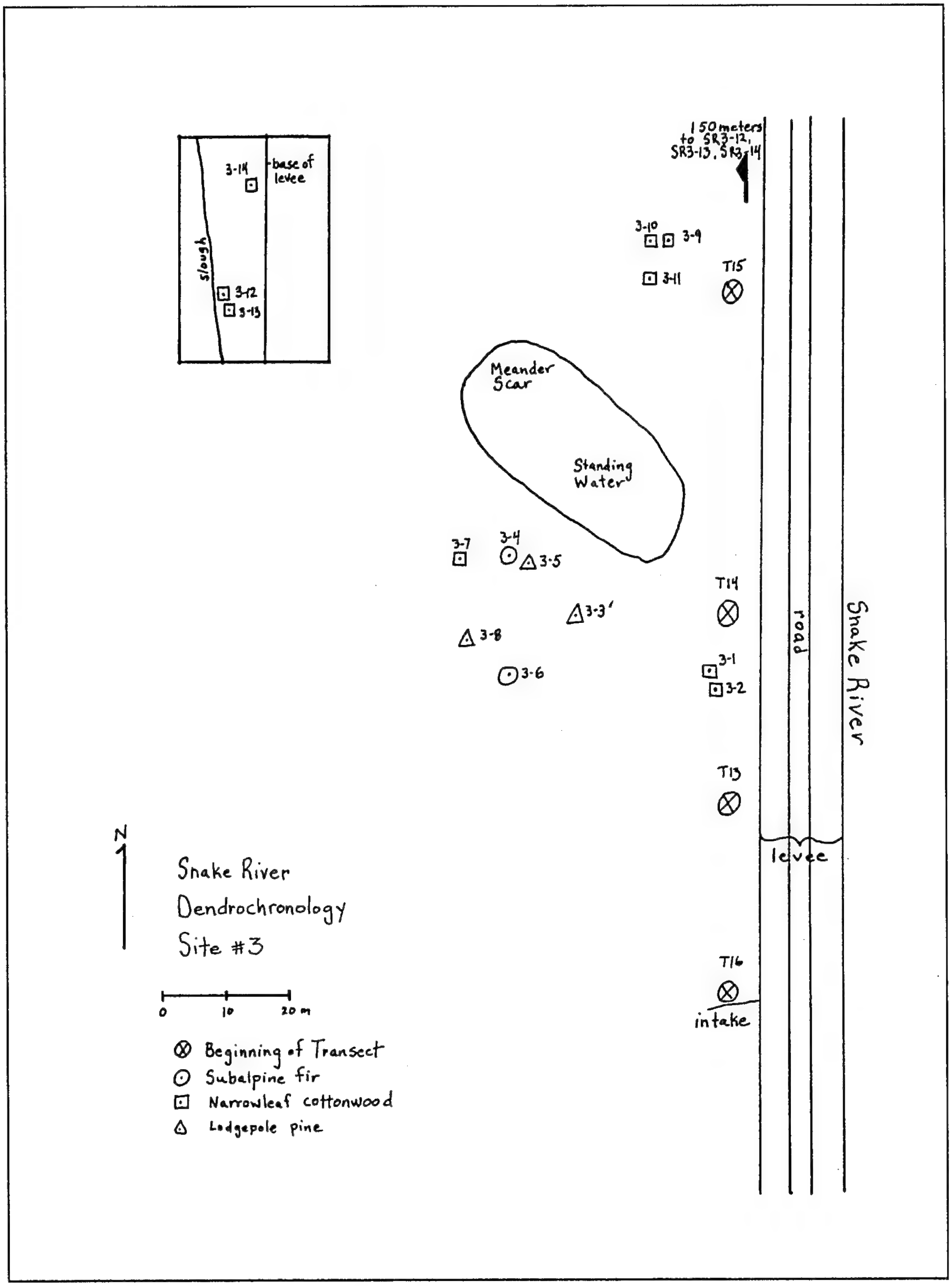

Figure 12. Sketch map showing location of start of vegetation transects 13 through 16 and location of trees sampled at Site 3

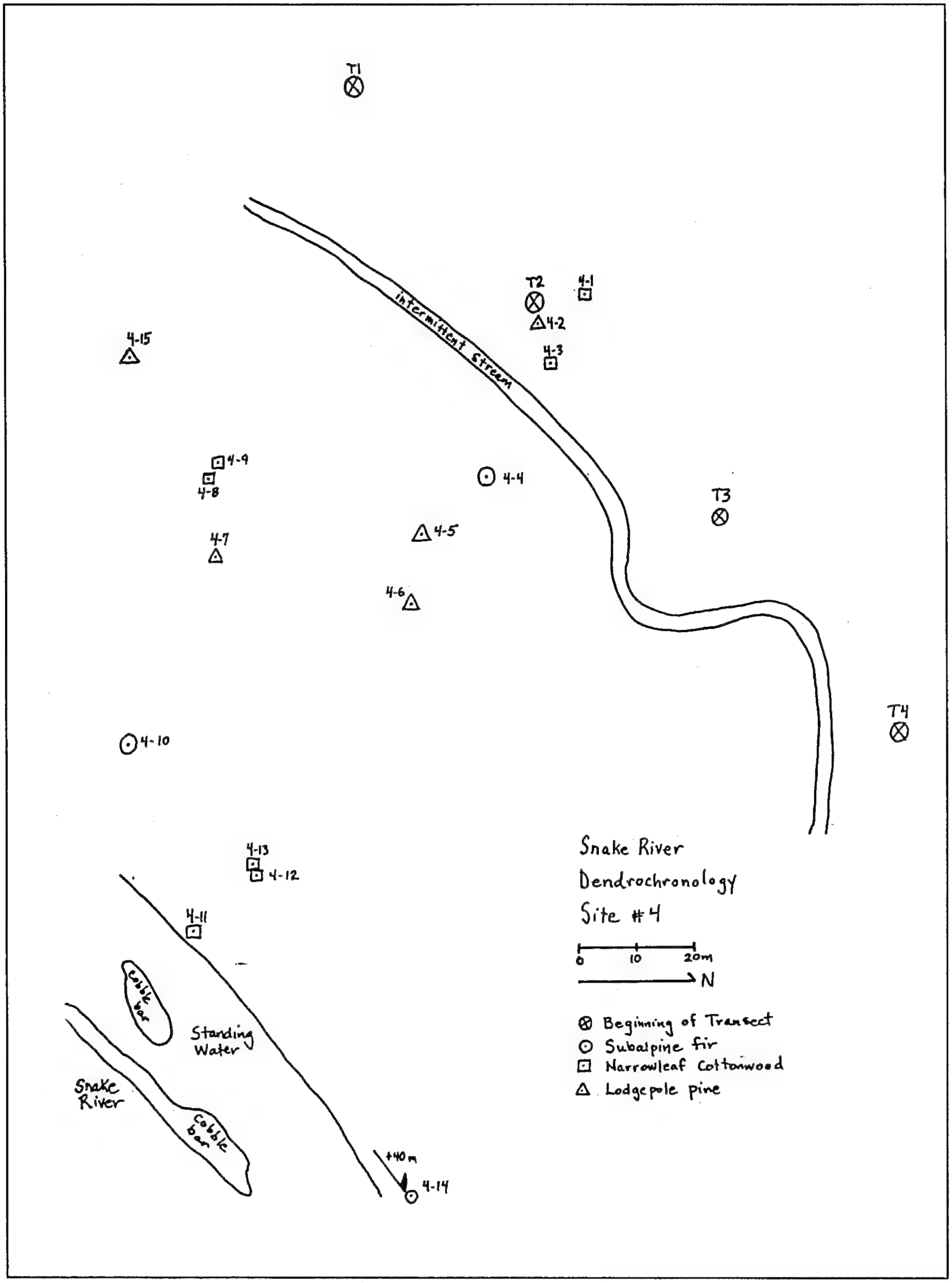

Figure 13. Sketch map showing location of start of vegetation transects 1 through 4 and location of trees sampled at Site 4

o. Conditions of tree growth.

p. Comments on local ecology and geology.

An attempt was made to develop comprehensive documentation for the trees in the field and to incorporate the documentation in this report. Such documentation is presented because of:

a. Current standards of the dendrochronological discipline.

b. The standards of the UW Dendrochronology Lab.

c. The potential for aid in answering questions about tree growth which might be generated as a result of this study.

This set of information has been developed for use at the UW Dendrochronology Lab and is similar to variables noted by Fritts (1976) and Schweingruber, Kairiukstis, and Shiyatov (1990). By providing additional data, such as latitude and longitude, and appending subsequent data from actual lab analysis the lab can raise the specimens to the standards of the International Tree-ring Data Bank and submit them for use by other investigators (cf. Grissino-Mayer 1993a).

Sample size and type

The number and type of trees were selected for each site according to the limitations on the total number available at the previously selected study sites (primarily applying to conifers) or with regard to obtaining a sample from among numerous trees of appropriate size (cottonwoods always occurred with higher frequencies than could be used). The tree-ring samples are listed in Table 2 and summarized in Table 3.

Ten to sixteen trees were sampled at each site. Narrowleaf cottonwoods were sampled with the highest frequency ($n = 30$), followed by subalpine fir (14), lodgepole pine (8), and black cottonwood (4), for a total of 56 trees for all 4 sites. The total number of cores extracted was 67; the total number of tree radii that resulted was 119. Slightly smaller numbers of radii were entered into different phases of the analysis according to core quality.

After preparation, a few cores thought to be well enough preserved during field examination were found to have small segments where deterioration was too advanced for stabilization. These were generally unusable for accurate aging and verification and crossdating of their whole sequence. Some with internal rot still had long sequences of very measurable "mature" rings or "sapling rings" that could be added to other considerations of average ring width for trees of that general age class. The actual number of cores extracted in the field was actually much higher since many cottonwoods had internal deterioration that caused the core to be discarded at the site.

Table 2
List of Tree-Ring Samples

Specimen	Species
SR1-1A	Subalpine fir
SR1-1B	Subalpine fir
SR1-1C	Subalpine fir
SR1-1D	Subalpine fir
SR1-2A	Narrowleaf cottonwood
SR1-3A	Narrowleaf cottonwood
SR1-3B	Narrowleaf cottonwood
SR1-4A	Narrowleaf cottonwood
SR1-4B	Narrowleaf cottonwood
SR1-5A	Black cottonwood
SR1-6A	Narrowleaf cottonwood
SR1-7B	Narrowleaf cottonwood
SR1-8A	Narrowleaf cottonwood
SR1-8B	Narrowleaf cottonwood
SR1-10A	Subalpine fir
SR1-10B	Subalpine fir
SR1-11A	Subalpine fir
SR1-11B	Subalpine fir
SR1-11C	Subalpine fir
SR1-11D	Subalpine fir
SR2-1A	Narrowleaf cottonwood
SR2-2A	Black cottonwood
SR2-3A	Black cottonwood
SR2-4A	Narrowleaf cottonwood
SR2-5A	Narrowleaf cottonwood
SR2-5B	Narrowleaf cottonwood
SR2-6A	Narrowleaf cottonwood
SR2-6B	Narrowleaf cottonwood
SR2-7A	Subalpine fir

(Sheet 1 of 4)

Note: SR = Snake River project index; SR1 = Study Site 1, Moulton Property; SR1-1AB = (Sr Site 1) - (tree core 1) (radii A,B) from coring through tree; SR1-1CD = (Tree core 2 from tree 1) (Radii C,D) from coring through tree again.

Table 2 (Continued)

Specimen	Species
SR2-7B	Subalpine fir
SR2-8A	Subalpine fir
SR2-8B	Subalpine fir
SR2-9A	Subalpine fir
SR2-9B	Subalpine fir
SR2-10A	Black cottonwood
SR2-11A	Subalpine fir
SR2-11B	Subalpine fir
SR2-12A	Subalpine fir
SR2-12B	Subalpine fir
SR2-13A	Narrowleaf cottonwood
SR2-14A	Narrowleaf cottonwood
SR2-15A	Narrowleaf cottonwood
SR2-15B	Narrowleaf cottonwood
SR2-16A	Narrowleaf cottonwood
SR2-16B	Narrowleaf cottonwood
SR3-1A	Narrowleaf cottonwood
SR3-1B	Narrowleaf cottonwood
SR3-1B	Narrowleaf cottonwood
SR3-2A	Narrowleaf cottonwood
SR3-2B	Narrowleaf cottonwood
SR3-3A	Lodgepole pine
SR3-3B	Lodgepole pine
SR3-3C	Lodgepole pine
SR3-3D	Lodgepole pine
SR3-4A	Subalpine fir
SR3-4B	Subalpine fir
SR3-5A	Lodgepole pine
SR3-5B	Lodgepole pine
SR3-6A	Subalpine fir
SR3-6B	Subalpine fir
SR3-6C	Subalpine fir

(Sheet 2 of 4)

Table 2 (Continued)

Specimen	Species
SR3-6D	Subalpine fir
SR3-7A	Narrowleaf cottonwood
SR3-7B	Narrowleaf cottonwood
SR3-8A	Lodgepole pine
SR3-8B	Lodgepole pine
SR3-8C	Lodgepole pine
SR3-8D	Lodgepole pine
SR3-9A	Narrowleaf cottonwood
SR3-9B	Narrowleaf cottonwood
SR3-10A	Narrowleaf cottonwood
SR3-10B	Narrowleaf cottonwood
SR3-11A	Narrowleaf cottonwood
SR3-11B	Narrowleaf cottonwood
SR3-12A	Narrowleaf cottonwood
SR3-12B	Narrowleaf cottonwood
SR3-13A	Narrowleaf cottonwood
SR3-13B	Narrowleaf cottonwood
SR3-14A	Narrowleaf cottonwood
SR3-14B	Narrowleaf cottonwood
SR4-1A	Narrowleaf cottonwood
SR4-1B	Narrowleaf cottonwood
SR4-2A	Lodgepole pine
SR4-3A	Narrowleaf cottonwood
SR4-4A	Subalpine fir
SR4-4B	Subalpine fir
SR4-5A	Lodgepole pine
SR4-5B	Lodgepole pine
SR4-6A	Lodgepole pine
SR4-6B	Lodgepole pine
SR4-7A	Lodgepole pine
SR4-7B	Lodgepole pine
SR4-7C	Lodgepole pine

(Sheet 3 of 4)

Table 2 (Concluded)	
Specimen	**Species**
SR4-7D	Lodgepole pine
SR4-8A	Narrowleaf cottonwood
SR4-8B	Narrowleaf cottonwood
SR4-8C	Narrowleaf cottonwood
SR4-8D	Narrowleaf cottonwood
SR4-9A	Narrowleaf cottonwood
SR4-9B	Narrowleaf cottonwood
SR4-10A	Subalpine fir
SR4-10B	Subalpine fir
SR4-10C	Subalpine fir
SR4-10D	Subalpine fir
SR4-11A	Narrowleaf cottonwood
SR4-11B	Narrowleaf cottonwood
SR4-12A	Narrowleaf cottonwood
SR4-13A	Narrowleaf cottonwood
SR4-14A	Subalpine fir
SR4-14B	Subalpine fir
SR4-15A	Lodgepole pine
SR4-15B	Lodgepole pine
SR4-15C	Lodgepole pine
SR4-15D	Lodgepole pine
	(Sheet 4 of 4)

Lab Methods

Sample preparation

Upon bringing the core and slab specimens back to the UW Dendrochronology Laboratory at the Department of Anthropology in Laramie, the team allowed evergreen cores to dry in the soda straw tubes 1 to 2 weeks. The foil at the end of the pine and fir tubes was opened to allow them to dry more evenly. This only partially complete drying was adequate for them to be glued to the grooved core boards without splitting resulting from further drying. The cottonwood cores were kept sealed and not dried since it was anticipated that

Table 3
Summary Data for Tree-Ring Samples

Tree Species	Site Name	Number of Cored Trees	Number of Cores	Number of Radii
Subalpine fir	Moulton	3	5	10
	Grayson	5		10
	Prime	2	4	8
	Teton Park	3	6	10
	Total	13	15	38
Lodgepole pine	Prime	3	5	10
	Teton Park	5	7	13
	Total	8	12	23
Narrowleaf cottonwood	Moulton	6	6	10
	Grayson	8	8	12
	Prime	9	9	18
	Teton Park	7	8	13
	Total	30	31	53
Black cottonwood	Moulton	1	1	1
	Grayson	3	3	3
	Total	4	4	4
TOTAL		55	62	118

Note: Number of radii adjusted to delete cores unmeasurable because of rotten spots, partial penetration into opposite side of large trees.

they would meet to be shaved down with razor blades, a step which can be done in large, clean swaths if the cores are still soft and moist.

While drying was in progress, the needed 10-doz grooved, core boards were manufactured and sanded (1-in. by 16-in. by 3/4-in. oak boards with approximately 1/8 in. routered groove). Fir and pine cores are commonly processed at the UW Dendrochronology Lab, so standard procedures were glued with white wood glue, clamped, and allowed to dry overnight. A label was printed for each specimen number and also glued to the core holder.

No difficulty was encountered in making the pine and fir rings visible for effective measurement. In most cases, sanding with increasingly finer grades of abrasive paper brought them to a high polish. A combination of razor cutting and staining with kerosene, experimenting with lighting angle and intensity, and various other techniques were used with more difficult rings (e.g., the light-colored, indistinct rings often encountered in the outermost sapwood).

Cottonwood cores are known to be difficult to read. For example, Baker (1990) and others recommend staining with a substance such as phloroglucinol and counting rings in bright light in the field immediately after the core is extracted and before any drying takes place. However, this procedure allows only ring counts and not measurements, so it was not usable in this case. A variety of other investigators have reported some success with razor blading

rather than sanding. Razor blading involves rotating the cores to maximize the visibility of ring boundaries, cutting at an angle, and rubbing with colored chalk. The fieldwork was predicated on the assumption that some combination of these techniques would work.

Several cottonwood test cores were affixed to the core holders, and a variety of experimental procedures was tried. After a workable set of procedures had been determined, the remaining cottonwood cores were prepared. Using a number of dyes for staining botanical thin sections, rubbing with colored chalk, angle cutting, polishing, and other techniques met with limited success. The best strategy for viewing the orientation of the numerous, small water-conducting vessels and other structures of this semi-ring-porous wood under the microscope was based on making a small cut with a razor blade before gluing and clamping the core board. The core was rotated until trimming a flat surface along the top of the mounted core would make the vessels clearly visible as vertical hollow tubes, i.e., the wood was placed with the transverse plane exposed, the same orientation as occurs in the living tree (cf. Fritts 1976; Core, Cote, and Day 1979).

By trimming the core surface with a new razor blade used for only a few specimens, the break between these vessel tubules and the thin band of non-vessel cells separating one ring from another were sufficiently visible for measurement. Staining with water or kerosene, then letting the "sheen" dry back a bit, or doing this followed by polishing with a buffing wheel and buffing compound proved helpful. In some instances, it appeared that buffing until the surface of the core heated up resulted in a differential discoloration of different cell types, further enhancing the visibility of the rings.

Reading the rings of the cottonwoods was still very difficult relative to any evergreen specimen. Numerous cores had to be measured and remeasured by different investigators, followed by the comparison of measurement graphs to identify disjunctures, followed by more remeasuring until the correct solution was attained.

Cottonwood slabs from the logged trees were readable following reduction with successively finer grades of sandpaper and emery cloth, followed by polishing on a buffing wheel. The vertical vessels were not so visible in this case, but natural discoloration from gradual decaying of the fallen log, plus application of the "heating mode" buffing made these specimens very readable.

Sample analysis

Basic computer documentation and analysis. Specific results of analysis are explained in the next section, and an outline of the basic procedures required to bring the tree-ring measurements through analysis is presented. More detailed treatments, including line-by-line command structure, can be found in UW Dendrochronology Lab manuals.

Tempering the impressive potential of tree-ring analysis is the very complicated analytical framework that it required. Much of the work involved with a more "traditional" approach to dendrochronology, e.g., crossdating for purposes of climatic reconstruction, might be accomplished by going from a computerized reading stage data to the International Tree-Ring Data Bank (ITRDB) Program Library. However, software of this type does not include adequate bar graph programs for visual crossdating, high-quality line graphs for an evaluation of growth form, or output of the data needed for an evaluation of growth rates ("rings per centimeter for all trees 20 to 40 years old," and other tailored results needed here).

Measurement of ring widths. The rings of all of the specimens were measured using a Henson optical rotary shaft encoder which had been reconfigured for a serial port interface with IBM compatible hardware. The interface electronics and related software for this device were designed and constructed at UW (Reher, Reher, and Rich 1993). A precision-pitch screw-driven reading stage holding the core is moved manually along and under the crosshair reticule of a variable power microscope. Varying lens powers are used depending on the condition of the specimen, but usually only relatively low magnification is needed.

Movement of the specimen under the crosshair, from one side of a ring to the other, requires only the pressing of the interface trigger button to record the distance the measuring stage has travelled (i.e., the width of the ring) to the nearest 100th mm; the measurement is then automatically stored in computer data files.

Various types of individual rings and cumulative 10-year increments were noted by making a mark on the core board next to the ring. The traditional system of making pinholes directly into the cores was not done because of the extremely tricky nature of the cottonwoods which would have led to a number of inaccurate, superfluous pinhole indicators on some cores on the first set of measurement runs.

Each data file is identified by naming it after the specimen number. ASCII compatible data sets are generated, with the date (actual if known, or an arbitrary start year to be changed later), and ring width listed in vertical columns. Two types of data files are produced by the UW Dendrochronology Lab software, with an automatically supplied *.dat or *.rm ("data" or "raw measurement") file. The two file types incorporate minor differences such as a separate column for individual date next to the corresponding measurement versus only a start year specified in the file header. One of the files generated is more easily entered into some of the graphics analysis packages used by the Dendrochronology Lab; the other is more compatible with the standard format used by the entry programs of the ITRDB Program Library.

Correction for angled measurement of central rings. The more central rings often cannot be measured along the standard track without introducing error because of the very definite differences in their diameter relative to outer

rings, and hence the angle which the crosshair travels across them. In the ideal situation where the increment core struck dead center on the central pith of the tree, this sort of error is minimized. The track of the measuring stage is essentially parallel to one cell-wall axis and perpendicular to the other axis all along the core; i.e., the measurement vector is the true radius of the tree and perpendicular to a tangent of the circumference. However, even with the experienced fieldhand consistently coming very near to the center of each tree, the angle of the core across the ring can inflate the width derived for these already large, early growth rings. This increment of exaggeration is small but significant given the measurements of this precision.

This fact is not addressed in the literature; apparently, standardization to remove the growth curve (recall discussion above) presumably also standardizes or mitigates this measurement error. It was decided to attempt to develop techniques to correct this measurement error so that the standardization was based on a more accurate extraction of the growth curve. A correction was thought to be more important than usual in a study to compare the high growth rates of a number of young trees from a mesic floodplain environment.

Maintaining exact placement and precision of the crosshair on the start of one ring and the end of the next does not allow for simply gradually rotating the specimen itself to keep the measurement vector perpendicular to the true ring diameter. However, a reading table platform was developed that had a high quality, ball-bearing circular, rotating base with enough stability to allow rotation of the sample sufficient for a more accurate measurement vector if great care was used in maintaining crosshair placement. Even more accurate was a combination of using the protractor reticule of a 10x handheld optical geological comparator to record correction factors based on standard geometric formulas. These formulas were programmed into a Minitab routine to correct a series of angled measurements as needed. The true value for ring width was established in this fashion for several innermost rings on about 20 percent of the specimens.

Initial verification of measurements. As is standard for tree-ring measurements, two people measured each core. It is standard to duplicate measuring as much as possible to avoid measurement error. In many cases, cottonwood cores were read by three individuals. Differences from major problems, for example when one person misses a faint ring, will be immediately apparent with graphical comparison or reviewing of measurement columns. Statistical formulas can be used to identify minor errors (Fritts 1976).

Given the precision of the measurement and the departures that automatically occur from such factors as the slightest difference in the measuring track along the same core, complete agreement on every measurement between two technicians is essentially impossible to achieve. This study used automatic flagging of all measurements which differed by 0.1 mm or more to relocate possible problems; then these rings were remeasured.

Comparison of two radii from the same tree was especially useful in verifying final measurement sequences. These procedures resulted in the correction of a small but consistent percent of the sequences, e.g., locating false or partially missing rings when outermost-ring/innermost ring counts did not yield the same total. For example, three of the fir and pine cores needed corrections of this type. Various other procedures were used to verify the two measurement sequences, including the ITRDB Verify Program files which were also produced for additional statistical evaluation (see below).

At several points it was possible to produce ASCII files with two columns based on date (year) and ring width, with a *.dat extension usable by GRAPHER software. The resulting preliminary line graph could be used to aid with an initial comparison of radii. If a faint ring had been missed on one radii, or a false ring separated from the "parent" ring, the peaks and valleys of the two graphs would be off by an increment of one from that juncture on.

Several methods then were available for entering any initial corrections to produce the final raw measurement data file. The most efficient editing used standard wordprocessing software such as Wordperfect 5.1 in ASCII text mode to enter corrections manually (except for correction of angled central ring measurements which could be done with a separate, custom program described above). An initial hardcopy and floppy disk copy of the ASCII file in vertical casewise (columnar) listing format were saved for purposes of initial review and saving of backup copies.

Final verification. The corrected raw measurement (*.rm) format ASCII file provided the needed format for entry into the ITRDB Program Library. The format has measurer's name, date measured, and the starting year for the sequence, followed by the column of measurements with a 999 end-of-file marker. Before proceeding to final documentation based on the *.rm file, the ITRDB Verify5 program was used to further examine the veracity of the ring measurement sequences and to obtain some basic statistics.

The Verify5 program uses regression analysis to compare two *.rm ring sequences, verifying the first file specified against the second, presumably more correct sequence. The results of a basic linear regression between the 'Y' file (first file) and 'X' file (second) are reported, and two confidence levels are supplied: 0.01 is recommended for evergreen species, and 0.05 for ring diffuse or porous diffuse species, such as cottonwood. Another section of the Verify5 report lists specific outliers in excess of the 95-percent confidence level.

Although the statistical output of the Verify5 routines allows for very useful, more intense evaluation of ring series, perhaps 1 out of 50 or 100 ring series from this or any other project appears to meet the significance level criteria. This is the case even with radii from the same tree with distinct rings and no erratic growth. Results that were obviously consistent according to several other types of analyses would have a very few rings that were a few hundredths or tenths off, and the comparison would be rejected. Correlation

coefficients exceeding 0.92 based on almost 70 rings will not be accepted by the program. The program was used to compare only radii from the same tree because of this characteristic.

After initial results, a number of tree radii were measured and remeasured, and outliers were worked and reworked, all without any real improvement in the outcome, until it was clear that measurement error was not contributing to the "lack of significance." The program's statistical hypothesis that "if the two sets of data represent the exact same distribution, the regression should indicate near-perfect agreement (r-value near 1.0, amount of variance explained near 100 percent)" (Grissino-Mayer 1993b) is not feasible for any of the reasonably sensitive tree measurements entered, or an error exists in the programming or in the application of the statistical assumptions and hypothesis underlying it.

The statistical tables in the Verify5 output files are a useful, quick reference for any specimen for which they are needed (mean width, median, variance, standard deviation, and mean sensitivity and other statistics). Before using any of the data in these appendices, please note that several trees had only one radius extracted, so this was "verified against itself" to produce the statistical table, and the "perfect correlation" of 1.0 is spurious with these single-radii specimens.

Format conversions. Most other applications in the ITRDB Program Library require a file in tree-ring lab "measurement format," which is a horizontal decade-wise listing with a more complex header (Grissino-Mayer 1993c) (UW Dendro. Lab *.m file naming convention). The vertical measurement files were converted to this format, and the documentation of each individual tree sample for the Snake River project is on file in an unpublished report at the U.S. Army Engineer Waterways Experiment Station.

Other file conversion routines are available in the ITRDB Program Library (Holmes 1993a); some were needed for various aspects of the analysis. Options in the UFD software utility allow reading five standard types of formats, as well as allowing the user to specify a custom format for any column-based ASCII file. The ITRDB ProgLib YUX software utility sets up a combined listing of several measurement sequences following a first column that specifies the date.

The casewise listing of the Snake River data is most useful for export to Grapher or Minitab software (see analysis below). This data is on file in an unpublished report at the U.S. Army Engineer Waterways Experiment Station. The UFD routine can be used to make a "universal vertical" format listing of a single tree sequence while multiplying or dividing by a constant. This was occasionally used to shift the decimal point before export to Grapher or some other program as needed.

Standardization of measurements. The powerful Arstan40 program was used to produce standardized indices and other statistical data (Holmes 1993b).

The Arstan Program provides several options for detrending and calculating standardized indices. Autoregressive modeling and other aspects of estimation of the mean value function are used to compare ring-width series in terms of the common signal while smoothing out endogenous stand disturbances.

Tree-growth rates, including to some extent endogenous variation, were of primary interest to this study rather than crossdating or climatic reconstruction. Accordingly, standardization was not as needed as in many dendrochronology studies. Fritts (1976), and many others discuss how various standardization techniques automatically remove some frequencies of climatic signal and how they "often obscure gradual growth changes...(Zahner 1988; Holmes, Adams, and Fritts 1986)."

However, the study goals were to:

a. Compare the results of applying various standardization techniques, and cursorily examine some aspects of climatic/hydrological variation in Jackson Hole.

b. Use Arstan40 to produce various additional statistics useful to a comparison of the tree growth at the four stands (e.g., autoregression coefficients).

c. Provide as much standard dendrochronological documentation as possible for use by future investigators.

The results of the Arstan analysis are subdivided by study site, although it also necessary to further subdivide some species/site groups because the Arstan40 Program allows for a maximum of only eight trees per run. The options used for this analysis are summarized at the start of each set of outputs. Other results and implications of the Arstan analysis are discussed further below.

Graphic analysis. Conversion processes were used at several junctures to export tree-ring width series to Grapher and produce line graphs of individual trees. At earlier stages, these graphs were used to aid in verification procedures, and at later stages to document growth forms, including both general age effect and "pulses" from endogenous or exogenous effects. Whenever possible, these graphic results (ASCII *.dat files) show two radii from the same tree.

Indices produced with the Arstan40 Program were extracted from the general output files and exported as columns of ASCII data to WP5.1 and then to Grapher for exploration of the effects of different detrending/smoothing options. After further editing, indices were exported to DBASEIII+ as ASCII *.txt files, and UW Dendrochronology Lab program SKPLOT converted indices to values of 0, 1, 2, and 3, depending on how many standard deviations of measurement were below the mean. These values were then used with a specialized Grapher symbol generation program to produce "skeleton plots,"

a specialized type of bar graph used since the first inception of tree-ring analysis to visually crossdate trees.

The emphasis on years from only the most extreme droughts (0 to 3 standard deviations below the mean) allows quick cross-checking of one specimen against another. These had less relevance for the project at hand but were of some use for several of the samples, for example, in examining the scale and timing of growth pulses.

Statistical analysis of growth rates. Finally, MiniTab and other software were programmed to accept casewise listings from the ITRDB conversions, and basic statistical analysis of growth rates could begin. Graphs of ring widths, dated casewise listings, and the other information produced by the basic analysis were used to set up comparisons by site and species, by basic tree age brackets, and by sets of specific calendar years. A basic statistical evaluation followed, although it was soon clear from the analysis that growth rates were patterned, and that these patterns supported conclusions from some of the other types of analyses performed. As with other portions of this description of methodology, primary results are discussed below.

4 Results and Conclusions

Stand Age and Successional Structure

Dating of individual trees allowed examination of the age structures of the samples obtained. There was no attempt to rigorously sample the extremely large numbers of trees that would have been required for a statistically valid approximation of the stand ages along the river. However, the samples that were obtained are thought to be a reasonable approximation of some aspects of tree stand ages at the study sites.

Since this study tended to maximize the data available by sampling some of the larger trees of each species at each site, the establishment dates of the older, original tree stands is implied by the results. Age structure needed to be established in any case so that the most appropriate brackets could be defined for comparisons of growth rates. As was discussed above, young trees in some contexts have much wider rings to begin with, and other age effects need to be allowed.

Examining the start years of the trees revealed some differences between the four sites. These are summarized in Figure 14 as frequencies of start years on a scale decades. These start years are approximate because of differing coring heights, estimates of central ring position when the true center was not quite achieved and so on, but probably accurate within 5 years or so. Simple subtraction of the approximate tree age must be adjusted upward 1 year to allow for the fact that the coring year counts in the calculation, e.g., a tree 10 years old in the fall of 1993 began growth in 1984, not 1983.

Site 1, the Moulton Property, contained three fir trees with five cores ranging in age from 39 to 72 years (establishment dates of about just before 1922 to 1945). Site 2, the Grayson Property, also had some of the older fir trees, with five cores from five trees ranging in age from 23 to 82 years (just before a range from about 1912 to 1971). Site 3, the Prime Property, possessed two fir trees where three cores ranged from only 18 to 19 years (about 1975 to 1976) and three pine trees where five cores demonstrated that the trees were about from 9 to 17 years (1977 to 1985). (Note that the scale of the frequency or y-axis in the graph for Site 3 is not the same as the other 3 graphs, to allow for the large number of comparable aged cottonwoods). Site 4, Grand Teton

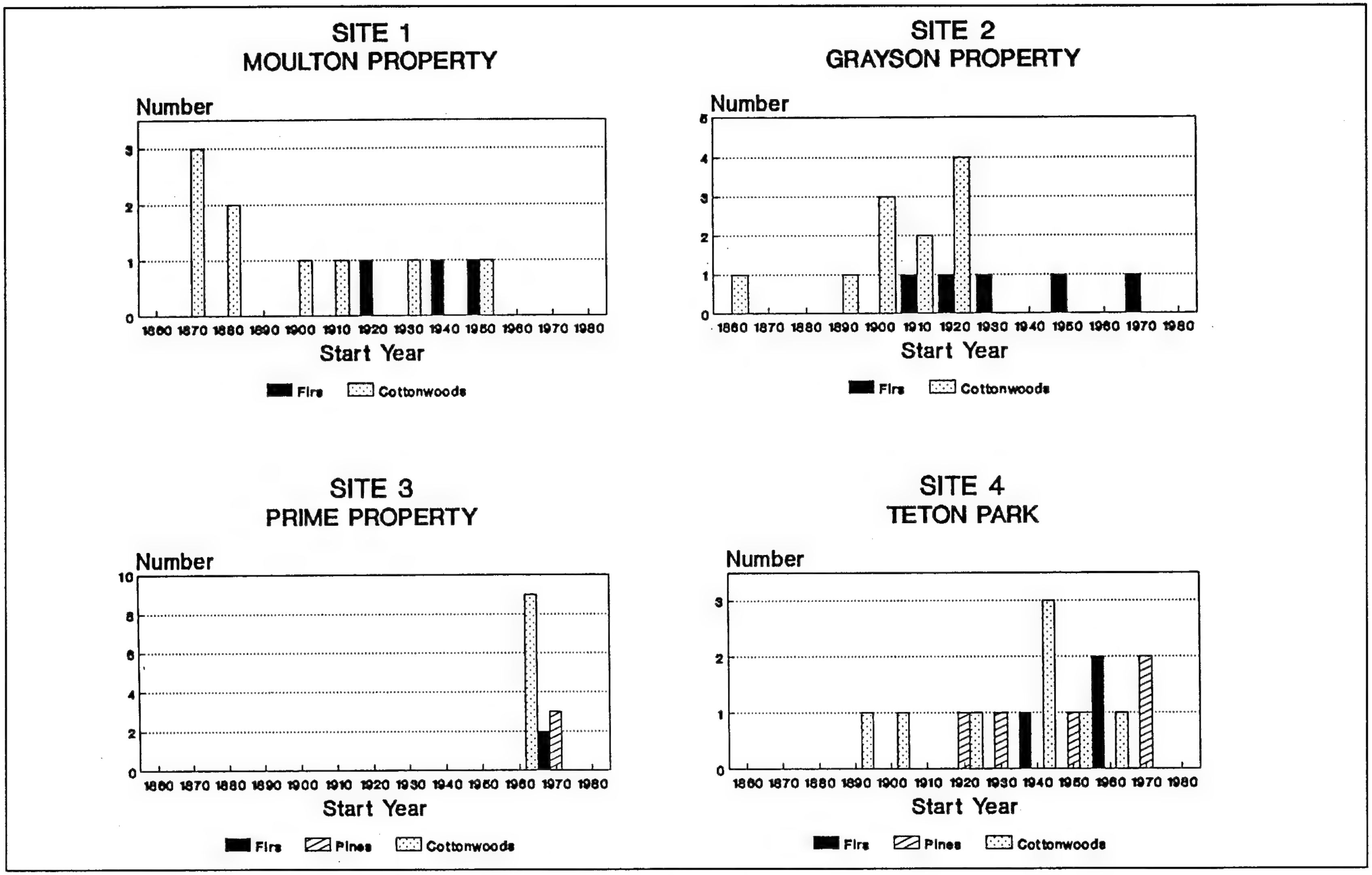

Figure 14. Bar charts summarizing age structure of sample trees at the four study sites

Park, yielded four cores from three firs ranging in age from 29 to 44 years (1950 to 1965) and seven cores from six pines ranging from 29 to 70 years (1924 to 1974).

The cottonwoods sampled at the sites are similar in some general respects. Cottonwoods at Site 1 have reached even older ages, about 61 to 118 years (A.D. 1876 to 1933). Those at Site 2 included one that was at least 126 years old (1868) while the other samples tended to be at least 67 years old (starting growth just prior to 1927). At Site 4, cottonwoods were sampled ranging in age from 96 years (growth started prior to 1898) to only 24 years in age (1970), while those at Site 3 tended to be younger, about 25 to 30 years (actual first measurement dates of 1964 to 1969).

It can be concluded that three of the sites had varying numbers of conifers available for sampling, but they were generally comparable in age, i.e., mature trees from 40 to 80 years of age, with a few younger ones. However, the average age of firs and pines at Site 3 is much younger than the conifers at these other three sites, and direct comparisons with the other sites might be misleading unless adjustments are made. Cottonwoods yielded essentially the same data.

One also might conclude that Site 3 has something approaching the structure of an even-aged stand, where disturbance of some sort led to the re-establishment of trees in this specific locale in the late 1950's or early 1960's. Logging or fire history usually proves to be the source of such stand-wide disturbance in forest management study, and perhaps logging during the construction of the levee system or a destructive flood that breached the levee system soon after it was built is responsible here. Some other disturbance such as staging areas for heavy equipment during levee construction or for gravel quarrying operations would also be a possibility.

Similarly, the bar charts in Figure 14 suggest that tree establishment in the other 3 sites in general has been relatively continuous across a number of decades with, however, a number of specific modes or peaks that might relate to disturbances or climatic episodes that led to several smaller pulses in tree establishment. A much larger area would have to be cored to determine whether the establishment area would have to be cored to determine whether the establishment of several trees during a certain limited time period was due to a favorable climatic situation or some other factor, or just an aspect of generally continuous establishment. However, a climatically controlled pulse is a likely scenario given what has been learned about flood plain seedling establishment (cf. Baker 1990).

By the same token, the sampling strategy used does not mean that a lack of small cottonwood saplings at the "upper end" of the bar chart indicates that no seedlings or saplings occurred. Cottonwood was so common that at most of the sites the tendency was not to sample cottonwoods below a certain size. Conversely, the cooperative research sampling transects demonstrate the same patterns of low numbers of proportions of seedlings and saplings at the

Moulton Property and the Grayson Property (Sites 1 and 2), and grazing pressure and increasingly dense, mature canopy coverage must be major factors in this pattern.

One pattern probably occurring at all of the sites is that of initial establishment by cottonwood stands, followed by conifer establishment some decades later. Although the details of logging history are unknown, it is still possible to speculate that increasing shading and the formation of topsoil through accumulation of dead leaves and other vegetation is needed for effective seedling establishment of pines and firs. The effects of flood control on the diversity and succession in riparian zones is the subject of another study.

Growth Form

A number of conclusions about growth form can be reached on the basis of the analysis of ring widths of the Snake River trees. All aspects of this study of growth form would benefit from further development, especially with regard to separating the specific climatic response signals and endogenous effects imbedded in the growth curves; however, even this cursory review offers useful general insight into the conditions of tree growth on the Snake River floodplain.

In a number of cases, the growth form of the riparian zone trees used for this study does not follow exactly the standard exponential decrease of ring width as tree circumference increases. There are several possible reasons for this, including the important fact that most of the trees are young relative to the age commonly used for dendrochronological analysis (i.e., 40 to 120 years versus 100 to 300 years or more). Trees can show a significant age-effect depression of ring widths within 10 or 20 years and usually within 50 to 75 years, but in some specimens it is not noticeable until after a century or more.

Also significant may be the fact that the marked exponential decrease from the age effect is most strongly developed in sensitive, dry-site trees in semiarid or arid regions, where the initial pulse of seedling establishment quickly shifts over to slow growth and maintenance of the canopy. Thus, other factors in this high-altitude, Jackson Hole setting should include the effects of overstory and understory density and the importance of growing season temperature.

The line graphs of ring widths described in Chapter 3 are the most accessible demonstration of the Snake River floodplain growth form. A quick perusal of these figures indicates that conifers tend to increase growth rate slowly 5 to 10 years or more, then to fluctuate between "good and poor growth years" before tapering off to what might be considered the start of an age-circumference effect. Since this is the case with almost every conifer of any age from Sites 1, 2, 3, and 4, it must be attributable to the factors affecting all sites and not an accident of site context.

This is not to say that there are not older firs and pines with an apparent "typical" age effect (SR4-15A-C) or with a gradual or a sudden shift to something resembling this form (e.g., possibly SR2-11A, B; 2-9A, B); however, there are other older trees that do not have the marked age shift seen in dry-site trees (e.g., 1-11A-C; 4-5A, B).

Similar overall patterns are seen in the cottonwood samples, with perhaps a few more trees with a gradual or a definite tapering of growth rates (c.f. the decrease in ring width with age expressed by SR1-2A; 1-5A; 2-2A; 2-10A; 3-1A; 3-2A; B; etc.). The largely complete or partial lack of such an effect until extremely late in tree life can be seen in other trees (e.g., 1-4A, B; 1-6A; 1-8A; 2-4A; 2-14A; 2-15A; 4-13A, and others).

Both the firs and pines, but to a much greater degree the cottonwoods, show strong tendencies toward rapid annual fluctuation centered around longer scale pulses. One assumes these longer cycles are related to climatic-hydrological effects and to endogenous effects such as canopy release. Ring width variability on an annual scale is especially noticeable in younger trees about 20 to 40 years of age, and what could be envisioned as growth pulses of about ± 10 years are also distinct. These multiple-year peaks are strongest in some of the cottonwoods (e.g., SR1-3A, 1-6A, 2-3A, 2-6A2-13A, 4-3A, and 4-12A). An intensive approach to standardization analysis could confirm these differences, and they could be attributed to such factors as the less-developed root systems of younger trees being most affected by seasonal fluctuations in groundwater levels.

The Arstan40 program was used to explore standardization of some of the trees which seemed to have a more definite age-effect growth form. An example is shown in Figures 15 and 16. The first figure shows actual ring widths on the upper scale (solid line) and the linear function (dashed line) used to calculate a mean value function and to calculate a set of standardized indices, as shown on the lower line graph (solid lines). The lower graph shows how a cubic spline function was used to fit a second detrending curve, and a second, smoother set of indices was produced. Figure 16 shows, on an expanded scale, how several degrees of spline stiffness can be used to smooth the first set of indices to varying degrees. It is clear from these graphs that in spite of various degrees of detrending, the fluctuation in the Snake River specimens on a 10- to 20-year scale remains very visible.

A final general conclusion from this phase of the analysis is that the growth forms of the individual trees, for whatever reasons, are consistent enough to allow for efficient comparisons of growth rates with minimal adjustments for between-site differences. This is also true to some extent for different age classes such that comparison on a gross level of overall average ring widths would be useful.

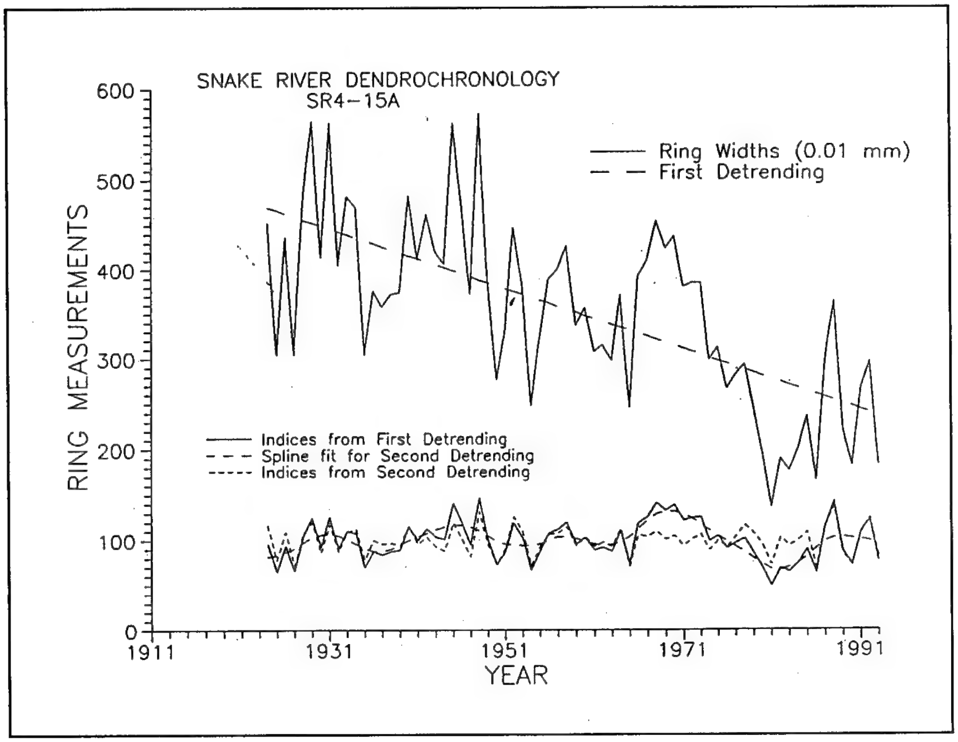

Figure 15. Plot showing results of standardizing ring widths for SR4 through 15A

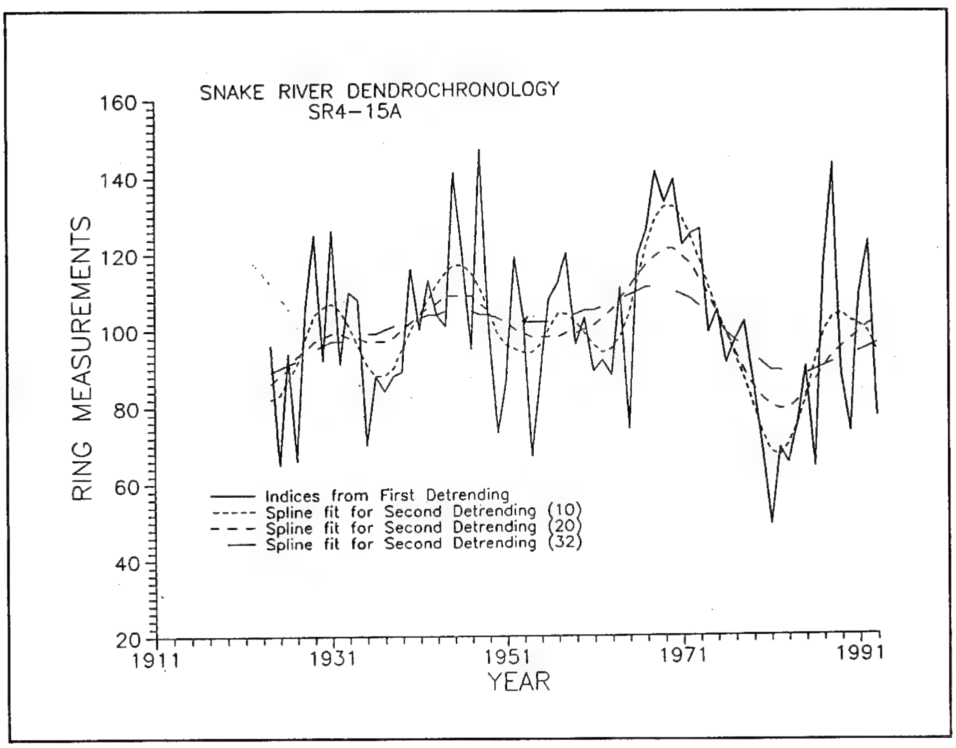

Figure 16. Plot with expanded scale showing results of standardizing ring widths from SR4 through 15A

Ring Width Variability

Having determined that the trees selected have generally comparable growth forms, similarities and differences between the Snake River sites also can be evaluated statistically for overall variability in tree response signals. Adjustments can be made if necessary by averaging site values and by identifying and discounting individual anomalous outliers. Fritts notes that "The more the tree has been limited by environmental factors, the more the tree will exhibit variation in width from ring to ring" (1976). Accordingly, measures of variability should indicate which sites and/or species have been most or least affected by the environmental stresses in the different site contexts.

Given the degree and type of variability seen in the line graphs of ring-width measurements, it is not surprising that the Snake River floodplain tree statistics are within the range of trees sensitive (variable) enough for cross-dating and other dendrochronological analysis. The Mean Sensitivity Index (MSI) statistic is a very basic but useful statistic for initial evaluation of tree-ring width variability. It is a measure of departure from one year to the next and can vary from 0.0 (no difference between years) to 2.0 (extremely variable, on the order of adjacent ring width values of 0.0 and 1.0). Values of 0.2 to 0.3 tend to be usable in dendrochronological studies, while values of 0.3 or more are best.

Since the growth form is reasonably similar for most of the trees, and since the MSI tends to incorporate all rings widths, it is assumed that endogenous "high frequency" variation has less effect on this statistic for these trees than overall exogenous climatic factors. However, it must be kept in mind that Site 3 is anomalous in terms of stand age.

The MSI statistic was calculated for the Snake River cores as part of verification and standardization routines. This statistic ranged from 0.195 at Site 3, to 0.267 at Site 4 for firs, and from 0.189 at Site 3 to 0.237 at Site 4 for pines. Cottonwoods ranged from as low as 0.155 to as high as 0.451 at the four sites.

Averaged sensitivities for sites and species are presented in Table 4. A ranking summary is also presented based on overall average and on the different tree species, where the lowest number means that site is the least sensitive (variable) and the less affected by environmental stress. It can be seen that the Prime Property (Site 1) has the least variable ring widths overall and, in fact, the lowest amount of sensitivity in species-specific categories. The other rankings tend to be consistent, with the Teton site being intermediate and second with relatively low environmentally stressed response functions in all categories. The Moulton Grayson Properties are also consistent, with a switch of ranking from third to fourth when cottonwoods and firs are compared. The actual MSI values show that they are quite close together in all cases (e.g., 0.235 versus 0.253), so this ranking switch in interspecific comparisons may be spurious or due to different ages of firs from each site. On the other hand, the large number of measurements underlying each MSI statistic may mean

Table 4
Mean Sensitivity Index (MSI)

Site	All Trees		Firs		Pines		Cottonwoods	
	MSI	(N)	MSI	(N)	MSI	(N)	MSI	(N)
Mean Sensitivity Averages								
1	0.300	(20)	0.235	(10)	--		0.365	(10)
2	0.305	(25)	0.253	(10)	--		0.340	(15)
3	0.207	(34)	0.195	(6)	0.189	(10)	0.221	(18)
4	0.276	(33)	0.267	(8)	0.237	(13)	0.325	(12)
Overall Site								
Average	0.266	(112)	0.240	(34)	0.216	(23)	0.302	(55)

Summary of Site Ranking[1]

Site	All Trees	Firs	Pines	Cottonwoods
1—Moulton Property	3	3	--	4
2—Grayson Property	4	4	--	3
3—Prime Property	1	1	1	1
4—Grand Teton	2	2	2	2

[1] (Ranks 1-4; rank of 1 = lowest MSI, least variable, least affected by environmental stress).

that these slight differences are real and that firs were slightly less stressed on the Moulton Property and cottonwoods, the opposite.

As just noted, the shorter tree sequences from this site could be a factor. Reworking of all other tree sequence data to allow for recalculation of the MSI statistic for the first few decades of growth was not attempted. The number of samples would have been greatly reduced since the most directly comparable and consistent control would have required using only trees established after levee construction. Comparative brackets of this type were established for growth rate comparisons, and MSI indices are used in this comparison, as explained below.

Grand Teton Park is ranked next in terms of sensitivity, having the second lowest average variability in all cases. The Moulton Property, Site 1, and the adjacent Grayson Property, Site 2, tend to have the third and fourth sensitivity ranking, respectively, except for the cottonwood categories where they are reversed, meaning that they are the most affected by climatic variability.

Evaluation of Growth Rates

Growth rates were examined in two basic ways: overall Mean Ring Width (MRW) and a number of rings per centimeter (Rcm) index. The two factors give somewhat differing, reciprocal views of growth, with average ring width being a gross measure of the rate of increase in circumference; larger average values indicated faster rates of growth during the warm season. Ermich et al. (1976) called the ring width average the "mean value of annual growth."

The number of Rcm is a somewhat more precise measure of how many rings occur across a standard increment. Slower growth leads to more (narrower) rings in the 1-cm increment, so in this case, larger numbers mean slower rates of growth.

The large number of rings from each site (i.e., about 2,000 measurements) could be expected to "average out" endogenous effects, age effects, and different species responses and, hence, to produce an index that is a reasonable measure of tree growth at each site. However, after calculating MRW for "trees on a site," and Rcm for each species, additional values were calculated for each species for different age and date brackets to ensure that the comparisons were valid (cf. Zahner 1988, Schuster et al. 1992). Zahner (1988) and Schuster et al. (1992) use "number of rings in outer 10 cm" of older trees to study growth during a specific time period.

Additional bivariate plots utilized the MSI as a base parameter plotted against Rcm to rank site growth rates graphically. A percentage of maximum attained growth was also used with the MRW and Rcm figures. As with MSI analysis above, sites were then ranked on a simple 1 to 4 continuum to allow for a summary overview of results. Finally, a set of averaged and summed rankings was used to establish relative growth rates at the sites.

Mean Ring Width

Comparisons of all trees

Average ring widths for all trees ranged from as low as 1.77 mm for the Grayson Property, Site 2, to as high as 4.215 for the Prime Property, Site 3, with the other sites falling between 2.1 mm for the Moulton Property (Site 1) and 2.952 at the Teton Park study area, Site 4 (Table 5). Overall, the fastest growth rates were found at the Prime Property, with slowest rates at the Grayson Property. The Moulton Site was closer to Grayson in having relatively slow growth, while the Teton Site was intermediate and had relatively fast growth.

As noted above, many trees in the Snake River sample tend to have suppressed growth for a decade or two (not the most typical growth curve), and then a spurt of wider rings eventually slows to impart something approaching

Table 5
Mean Ring Width (MRW)

Site	All Trees	(N)	Firs	(N)	Pines	(N)	Cottonwoods	(N)
				Ring Width, mm				
1	2.100	(20)	2.678	(10)	--		1.510	(10)
2	1.770	(25)	1.945	(10)	--		1.654	(15)
3	4.215	(34)	3.647	(6)	5.250	(10)	3.830	(18)
4	2.952	(33)	2.755	(8)	3.665	(13)	2.310	(12)

Percentage of Maximum Attained Growth[1]

Site	All Trees, %	Firs, %	Pines, %	Cottonwoods, %
1	50.0	73.4	--	39.4
2	42.0 (2.4)	53.3	--	43.2
3	100.0	100.0	100.0	100.0
4	70.0	75.5	69.8	60.3

Magnitude of Growth-Rate Difference[1]

Site	All Trees Magnitude (x)	Firs	Pines	Cottonwoods
1	2.0	1.4	--	2.5
2	2.4	1.9	--	2.3
3	1.0	1.0	1.0	1.0
4	1.4	1.3	1.4	1.7

[1] 50 percent indicates that site had a MRW about 1/2 of the mean for the site with largest value, or could be said to be growing about two times as slow.

an age effect to the samples. On one hand, overall comparison of large samples of rings will tend to submerge this age affect making all site data comparable. On the other hand, a closer examination of the site samples will show that Site 3 (Prime) had enough younger trees to appear to make it a bit more divergent than it actually is, and an age effect must be allowed for.

These relationships are well demonstrated in Figures 17a and b. Figure 17a shows the relationship implied along each axis, where an increasing MSI shows increasing effects of environmental stress and increasing ring width argues for generally higher rates of growth. As would be predicted, these two variables exhibit a negative relationship, i.e., the slope of a line fit to the site values would show that increasing environmental response correlates with decreasing growth rates. More sensitive trees tend to have slower growth than trees growing under more optimal conditions. Figure 17b uses foreshortened axis scales (i.e., not starting the axis origin at 0.0) so that the site values are spread out more and the relationships between them are more discernable. Both graphs clearly indicate that the highest growth is at the Prime Site, with Grand Teton intermediate and the Moulton Site and Grayson Site most comparable and with the slowest growth rates.

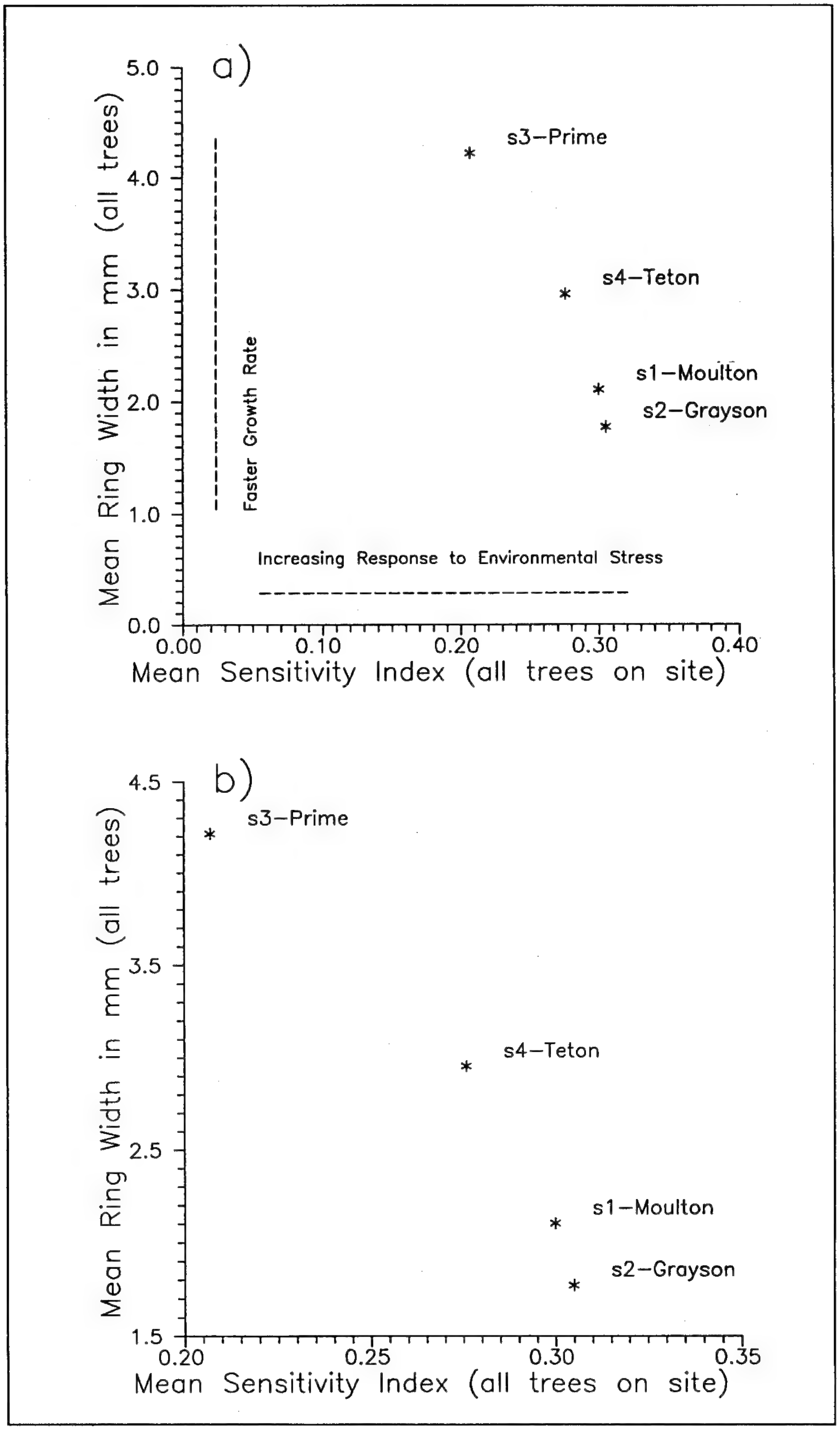

Figure 17. Bivariate plots of mean sensitivity and ring width for all trees from each site

Tabular comparison of species differences

Further analysis based on each species is also summarized in Table 5. The MRW for firs ranges from as small as 1.945 mm at Site 2, the Grayson Property, to as large as 3.647 mm at Site 3, the Prime Property. Pines were available at only two sites, and the smallest rings were 3.665 mm for MRW at Site 4 (Grand Teton), and 5.250 mm at Site 3 (Prime). Cottonwood MRW ranged from as small as 1.51 mm at Site 1 (Moulton) to as large as 3.83 mm at Site 3 (Prime).

Graphic comparison

Some finer details emerge form the species-specific comparison. Site 3 (Prime) firs have a higher growth rate (Figure 18a), but it is not a divergent from the other sites as it was in overall rankings (Figure 17). Site 4 (Teton) and Site 1 (Moulton) are very similar with regard to fir growth rates (Figure 18a). However, the same interspecific relationships are summarized in Figures 19a and b. Patterns similar to those just noted for "all trees" are preserved, including the negative relationship between sensitivity to environmental stress and growth rates. The higher growth rate at Site 3 (Prime Property) is still apparent, as is the intermediate growth at the Teton Site (Site 4).

It follows that differences in cottonwood growth contribute most to the separation of the Prime Site, and this pattern can be seen in the cottonwood values shown in Figure 18b, where the site once again distinctly differs from the other sites. The specific seasonal groundwater regime and perhaps understory/overstory conditions that affect the seasonal response patterns of fir species, may be less deleterious at the sites than the specific conditions that can affect the seasonal responses of cottonwood.

Finally, Figures 19(a) and (b) plots both fir and cottonwood on the same set of graphs, one Figure 19a showing the general patterning, and one Figure 19b showing logarithmic curves fitted to the two species clusters. The curves more clearly show the negative correlation between MSI and MRW mentioned above. The figure again clearly demonstrates that growth rates are highest at Site 3 (Prime), and lowest at Site 1 (Moulton) and Site 2 (Grayson), while also showing that growth conditions are much better for fir at Site 1 (Moulton) than for cottonwood.

Placing the two data sets and the fitted curves together also demonstrates that firs tend to be less sensitive to environmental stresses and to have thinner rings. Differences in ring width are probably just due to the nature of species-specific cellular growth patterns, while the differences in the standardized MSI statistic indicate seasonal climatic regime that is slightly more favorable for fir growth. A more detailed analysis of climatic data would be needed to identify the specific seasonal temperature and moisture patterns involved.

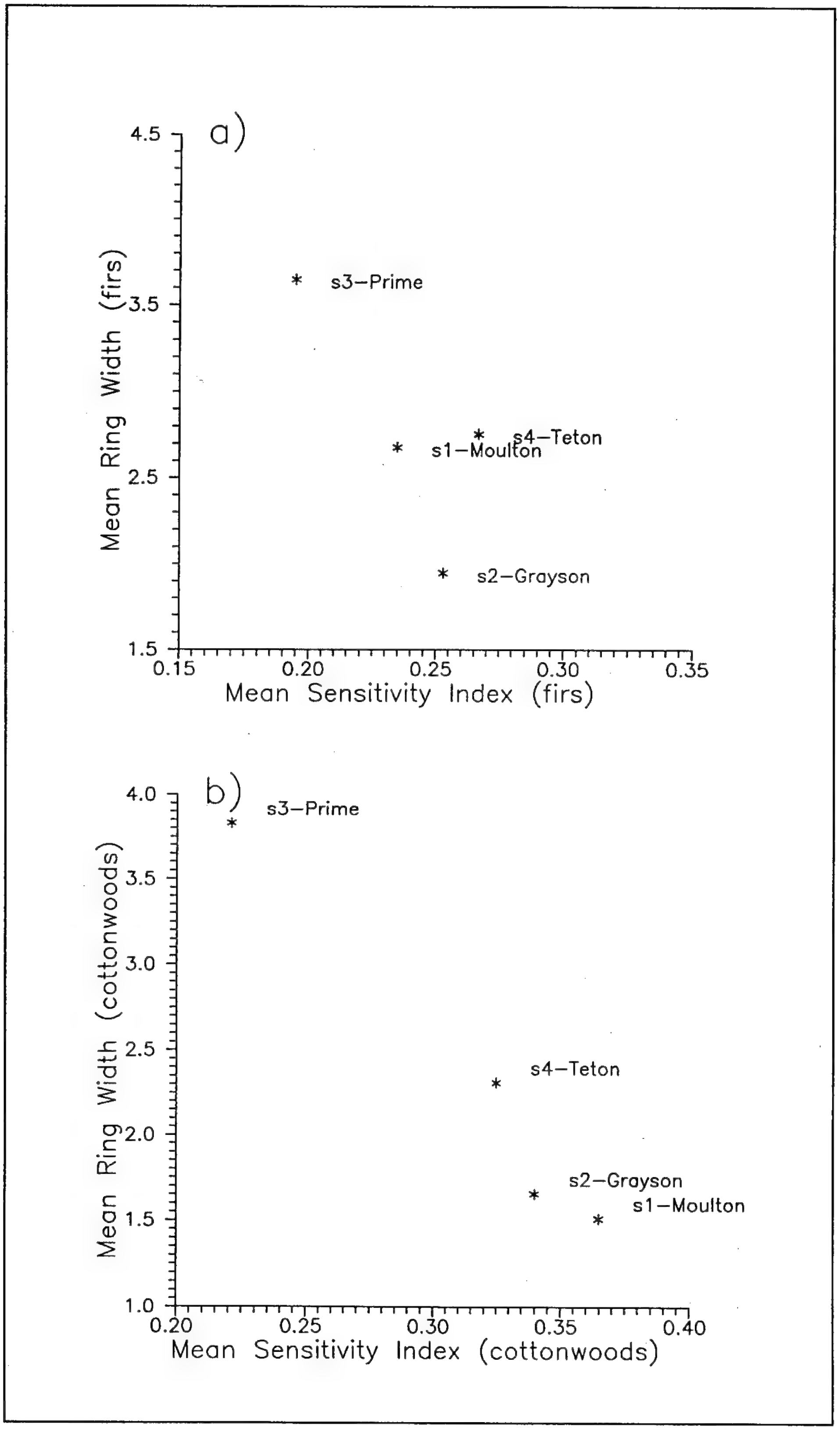

Figure 18. Bivariate plots of mean sensitivity and ring width for firs (a) and cottonwoods (b)

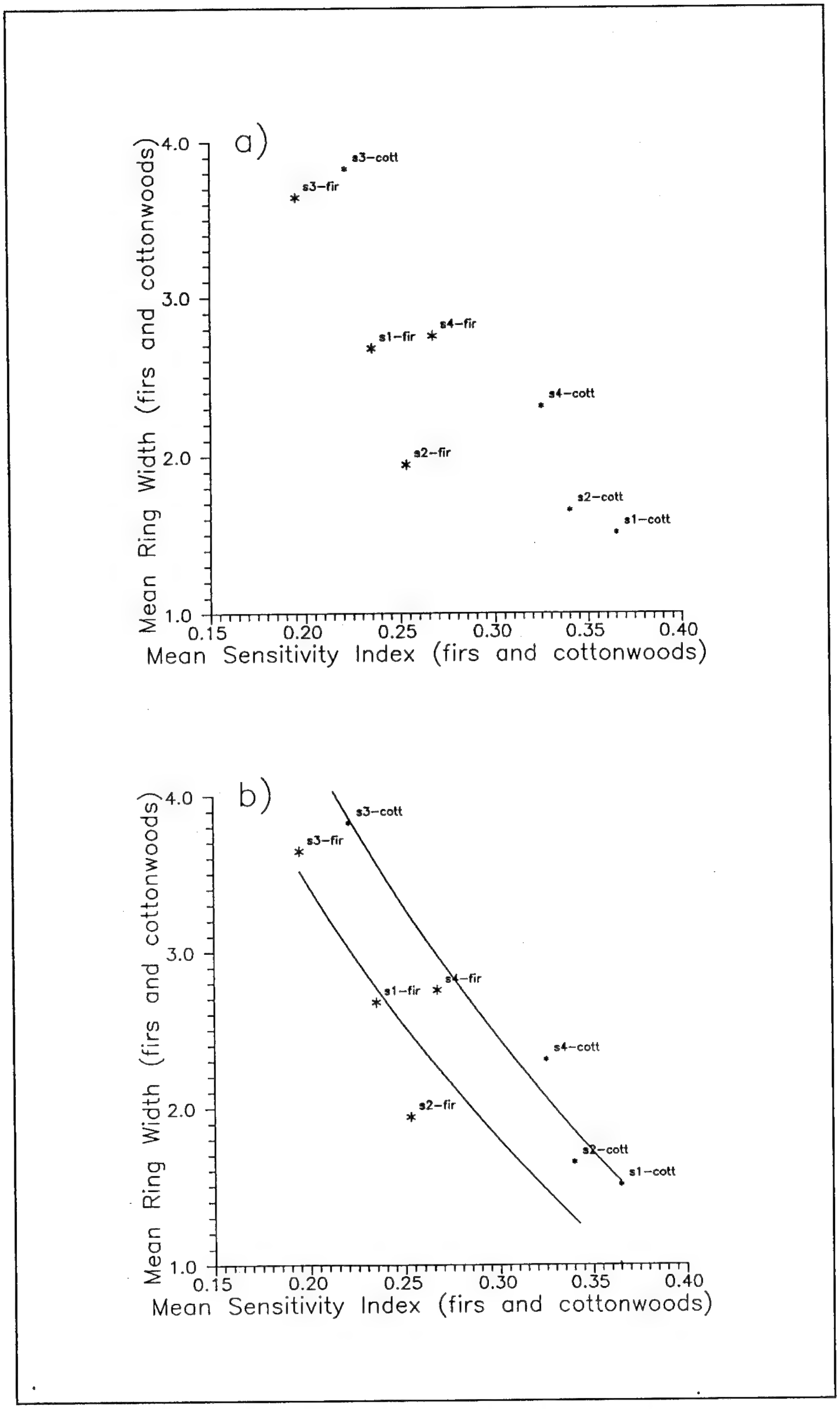

Figure 19. Bivariate plots of mean sensitivity and ring widths combining firs and cottonwoods

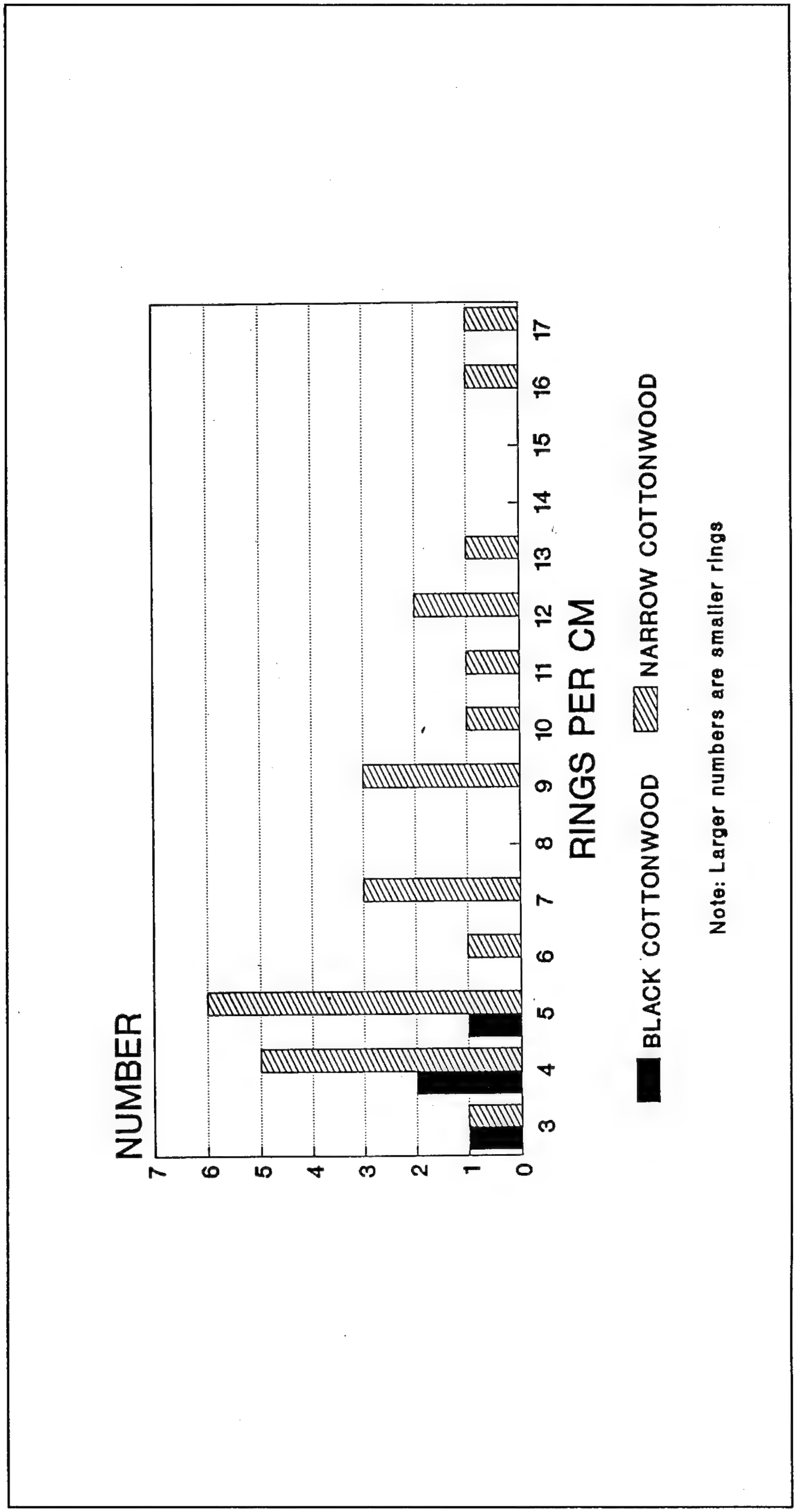

Figure 20. Bar graph comparing growth of black and narrowleaf cottonwood trees over 50 years old

Percentage of maximum growth and magnitude of growth-rate differences

Table 5 uses the site with the largest growth rate in each category as the "expected maximum rate" to express other site rates as a percentage of that maximum. This allows a more readily interpretable evaluation of growth rates at each site. Another section of the table translates the ring widths into a "magnitude" of the growth differential. Again, caution is advised against too literal an interpretation of these specific numbers since inherent age effects (e.g., the larger complement of younger, faster growing trees at Site 3) and other factors could be skewing the results. However, it can be argued that the percentage figures are directly interpretable as growth-rate differentials at the four sites, allowing for:

a. The selection of reasonably comparable trees specimens whenever possible.

b. The large samples of individual measurements in each analysis.

c. The consistent results emerging from the various types of analysis.

The percentage figures show that cottonwood growth rates at three of the sites are only about 40 to 60 percent of the rate at Site 3, the Prime Property. Fir growth rates tend to be somewhat higher, but still only 50 to 75 percent of the maximum site growth rate in the Snake River samples. These seem a rather dramatic departure, and major differences in growth conditions must be the cause. Though it is unclear how this differential compares with other riparian sites, in one recent study differences of about 10 to 15 percent between even-aged conifer stands were thought to be worthy of consideration for forest management policies (Honaker 1993). The differences in this case were caused by the effect of slope and aspect on moisture balance. Translated as magnitude differences, the data indicate that the trees at the other site, Site 3 (Prime) were growing 1.3 to 2.5 times as fast as the same species at the other sites (See analysis of age effects in the next section).

Number of Rcm

An index of tree growth based on some type of count of number of Rcm has been used as an analytical tool in some tree growth studies. It would be expected that the Rcm data would be the reciprocal of the ring width data (larger numbers mean narrower rings and slower growth), and that these data would provide much the same information about tree growth. However, the Rcm index provides for a more standardized unit of comparison than simple ring widths, which can come from trees of very different diameter and ages. It would also make these data more comparable to other studies and more effort went into this phase of analysis. The Snake River project had the advantage of having all rings measured incrementally, so it was relatively simple to set

up a program which added all the ring widths to get total core length, and then divide by the number of entries to provide the Rcm index.

Comparison of all trees and species differences

As was the case with other types of analysis, this project started with a gross comparison of all trees, having demonstrated that the broad patterns which emerged would be a reasonable overall representation of tree growth at the different sites. More refined analysis then followed based on different species and age/date brackets. Sample sizes often decrease with these more specific brackets because of sites which did not have all four species (the two cottonwood species being lumped in all analyses in any case), or which did not have trees old enough to fit some of the brackets. A set of statistical evaluations was then added to the sequence of analyses to allow for a more precise assessment of differences.

The Rcm data are summarized in Tables 6 and 7. The average Rcm for all trees range from 2.45 at Site 3 (Prime) to 6.01 at Site 2 (Grayson). Rcm for all firs ranged from 2.75 Rcm at Site 3 (Prime) to 5.29 at Site 2 (Grayson), and cottonwood values ranged from 2.63 Rcm at Site 3 (Prime) to 7.52 at Site 1 (Moulton). These results are similar to the other analyses, of course, showing higher growth rates at Site 3 and lower rates at Sites 1 and 2. The two sites with lodgepole pine also show higher growth rates at Site 3 (Prime), and lower growth rates at Site 4 (Teton).

More refined brackets were based on developing programs which selected for:

a. Growth of older firs during the period 1950 to 1970.

b. Cottonwoods growth 1950 to 1970 (for all trees with a start year before at least 1960).

c. Growth for all firs and cottonwoods during an "age-grade" of 20 to 30 years of age (i.e., all trees during this portion of their life span, regardless of the actual date when they started growing).

d. Youngest trees (basically growth for firs that started growing from after 1970 to 1993, and cottonwoods that started growing after 1960).

It is recommended that comparisons for conditions during and after levee establishment, comparisons for different, specific age brackets so that growth curves are factored out, and other types of comparison are made. With the framework of different site contexts set up by the Corps of Engineers, the Snake River dendrochronological study should provide sufficient information to answer very specific questions about the effects of levees on tree growth. Future work based on comparison of robustly standardized indices and climatic data by year or decade would allow even more detailed comparisons.

Table 6
Number of Rings per Centimeter (Rcm)

All Trees

Site	All Trees[1]	Firs and Cottonwoods Only
1	5.69	5.69
2	6.01	6.01
3	2.45	2.66
4	3.85	4.14

1 Calculated as weighted average from species-specific data/sample size.

Subalpine Firs

Site	All Firs	1950-1970[1]	20-30 Yrs.[2]	Youngest Trees[3]
1	3.86	3.64	2.87	--
2	5.29	5.15	3.37	4.93
3	2.75	--	--	2.75
4	3.61	--	2.69	3.60

(Continued)

1 Comparison of oldest trees, bracket 1950-1970.
2 Comparison of medium-aged trees, bracket 20-30 years old.
3 Comparison of youngest trees, all years.

Table 6 (Concluded)

Lodgepole Pines				
Site	**All Pines**	**1950-1970**	**20-30 Yrs.**	**Youngest Trees**[3]
1	--	--	--	--
2	--	--	--	--
3	1.93	--	--	1.93
4	3.00	--	--	3.39

[3] Comparison of youngest bracket, all years.

Cottonwoods				
Site	**All Cottonwoods**	**1950-1970**[1]	**20-30 Yrs.**[2]	**Youngest Trees**[3]
1	7.52	6.45	6.31	3.68
2	6.50	7.64	5.74	--
3	2.63	--	4.28	2.63
4	4.50	4.53	4.26	3.14

[1] Comparison of trees with start year before 1960, bracket 1950-1970.
[2] Comparison of all trees, bracket 20-30 years old.
[3] Comparison of youngest trees, all years.

Table 7
Percentage of Maximum Growth (%) and Magnitude of Growth Differences (x)

All Trees

Site	All Trees[1] %	All Trees[1] magnitude (x)	Firs and Cottonwoods Only	
1	43	2.3	47%	2.1
2	40	2.5	44	2.3
3	100	1.0	100	1.0
4	64	1.6	64	1.6

[1] Calculated as weighted average from species-specific data/sample size.

Subalpine Firs

Site	All Firs		1950-1970[1]		20-30 Yrs.[2]		Youngest Trees[3]	
1	71	1.4	100	1.0	94	1.1	–	–
2	52	1.9	71	1.4	80	1.3	56	1.8
3	100	1.0	–	–	–	–	100	1.0
4	76	1.3	–	–	100	1.0	76	1.3

(Continued)

[1] Comparison of oldest trees, bracket 1950-1970.
[2] Comparison of medium-aged trees, bracket 20-30 years old.
[3] Comparison of youngest trees, all years.

Table 7 (Concluded)

Lodgepole Pines

Site	All Pines		1950-1970		20-30 Yrs.		Youngest Trees[3]	
1	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–
3	100	1.0	–	–	–	–	100	1.0
4	64	64	–	–	–	–	57	1.8

[3] Comparison of youngest bracket, all years.

Cottonwoods

Site	All Cottonwoods		1950-1970[1]		20-30 Yrs.[2]		Youngest Trees[3]	
1	35	2.9	70	1.4	68	1.5	71	1.4
2	40	2.5	59	1.7	74	1.3	–	–
3	100	1.0	–	–	100	1.0	100	1.0
4	58	1.7	100	1.0	100	1.0	84	1.2

[1] Comparison of trees with start year before 1960, bracket 1950-1970.
[2] Comparison of all trees, bracket 20-30 years old.
[3] Comparison of youngest trees, all years.

The smaller samples in some brackets make the interpretation of the summary data in Tables 6 and 7 a bit more difficult, but it can be seen that fir growth in the age/date brackets is comparable to overall growth, with the exception of fewer rings/cm in the 20 to 30 years age bracket, i.e., wider rings and faster growth during this age span. Somewhat atypical, slower growth for the first 10 or 20 years is usually supplanted by a growth spurt for several decades following.

Other more subtle conclusions can be discerned by using the finer brackets, e.g., looking at only the youngest trees indicates that Site 2 (Grayson) has recently been more productive for fir growth than it was in the past. This may be due to greater soil moisture from canopy shading outweighing the effects of less sunlight and also understory competition. Fir growth for the period 1950 to 1970 was also slightly better than the overall average for all fir growth.

The cottonwood data (Tables 6 and 7) show that tree growth during 1950 to 1970 was slightly higher at Site 1 (Moulton) than the overall average, but it appears to have been the same or slightly worse at the other sites with samples of this age. Trees 20 to 30 years of age tend to show the same wider rings from the growth surge that was noted for the firs, except for Site 3 (Prime) where a very noticeable depression in growth rate is evident when compared to overall trends. Since this site tended to have mostly younger trees, the lower growth rate in the 20 to 30 year age bracket is not based on trees of different ages spread across a long series of decades (i.e., something affecting all trees of this age); rather, it is a reflection of factors during the last 2 decades. Increasing competion from new understory in the years after it had been scoured out by a flood or some similar process could be the cause.

For trees 20 to 30 years, Site 3 (Prime) had essentially the same growth rates as those for Site 4 (Teton). In summary, Site 3 (Prime) always tends to have the highest growth rates, but more careful consideration of age brackets shows that it was not always as divergent as it appears when overall averages are considered. When youngest trees from all sites are viewed, i.e., when the last 2 or 3 "post-levee" decades are considered for all sites together, Site 3 once again clearly has conditions more conducive to seedling and sapling growth.

Comparison of percentage of maximum growth rate and magnitude of difference

A section was appended to Table 6 which lists in adjacent columns the site/species comparisons as percentage and magnitude of difference (again in reciprocal fashion relative to MRW comparisons). These figures reveal that overall fir growth at Site 1 (Moulton), Site 2 (Grayson), and Site 4 (Teton) tended to be about 50 to 75 percent slower than at Site 3 (Prime), and that cottonwoods tended to grow about 40 to 60 percent slower. Converted to magnitudes of difference, growth at 3 sites was 1.3 to 1.9 times more limited for firs, and 1.7 to 2.9 times slower for cottonwoods.

Lack of firs of older age did not allow for effective comparison in the 1950 to 1970 and 20 to 30 year old brackets, but the youngest trees (i.e., about 1970 to 1993, 10 to 20 years old) show no appreciable difference from the overall results. A closer look at what age/date brackets were obtained is still more sensitive to age effects at Site 3 (Prime), and it appears that percentage differences of about 20 to 40 percent, or difference magnitude indices of 1.2 to 1.7 may be a more accurate characterization of departures of the other sites from the maximum growth rates sustained at Site 3, at least for the age brackets used.

Comparison of two cottonwood species

The few black cottonwoods encountered, all from Site 1 (Moulton) and Site 2 (Grayson), were examined to see whether there were any major differences from narrowleaf cottonwood. Figure 20 indicates that the four large black cottonwood sampled were all in the upper range of cottonwood ring width for trees at least 50 years old (e.g., large rings of only 3 to 5 cm). However, this is also in the main mode of the narrowleaf ring sizes, and black cottonwood is a small portion of the sample of cottonwoods of comparable age (about 15 percent). It was decided to leave black cottonwoods combined with the other older cottonwoods.

There may be some species-specific characteristic making this species more adaptable to the Jackson Hole growth regime, but it is likely that a larger sample and sampling trees of different ages might blur the distinction between the two species to some extent. It might also be noted that removing these four trees from the analysis would have a small but definite effect in the direction of emphasizing the slow growth rates at Sites 1 and 2.

Bivariate analysis of species differences

Interpretation of the general patterns discussed above can once again be enhanced with an intensive graphic analysis. Beginning with a plot of MSI and Rcm for all trees, Figure 21 shows that there is a positive correlation between mean sensitivity and Rcm, as would be expected. A larger response to environmental stress is correlated with slower growth and narrower rings, hence, a higher Rcm index (as indicated in the axis labels for Figure 21a). Figure 21b shows the same data with foreshortened axes to enhance differences between the sites. The divergence of wide rings at Site 3 (Prime) and narrow rings at Site 1 (Moulton) and Site 2 (Grayson) are once again apparent.

A comparison of firs and cottonwoods is presented in Figures 22a and b, plotting species-specific MSI against Rcm for all trees from that group. Here the relatively favorable conditions for fir growth at Site 1 (Moulton) can be differentiated from the fact that it had the slowest cottonwood growth, and other aspects of the growth patterns begin to emerge. Figure 23a depicts the two species' growth curves on one graph, and Figure 23b shows the result of

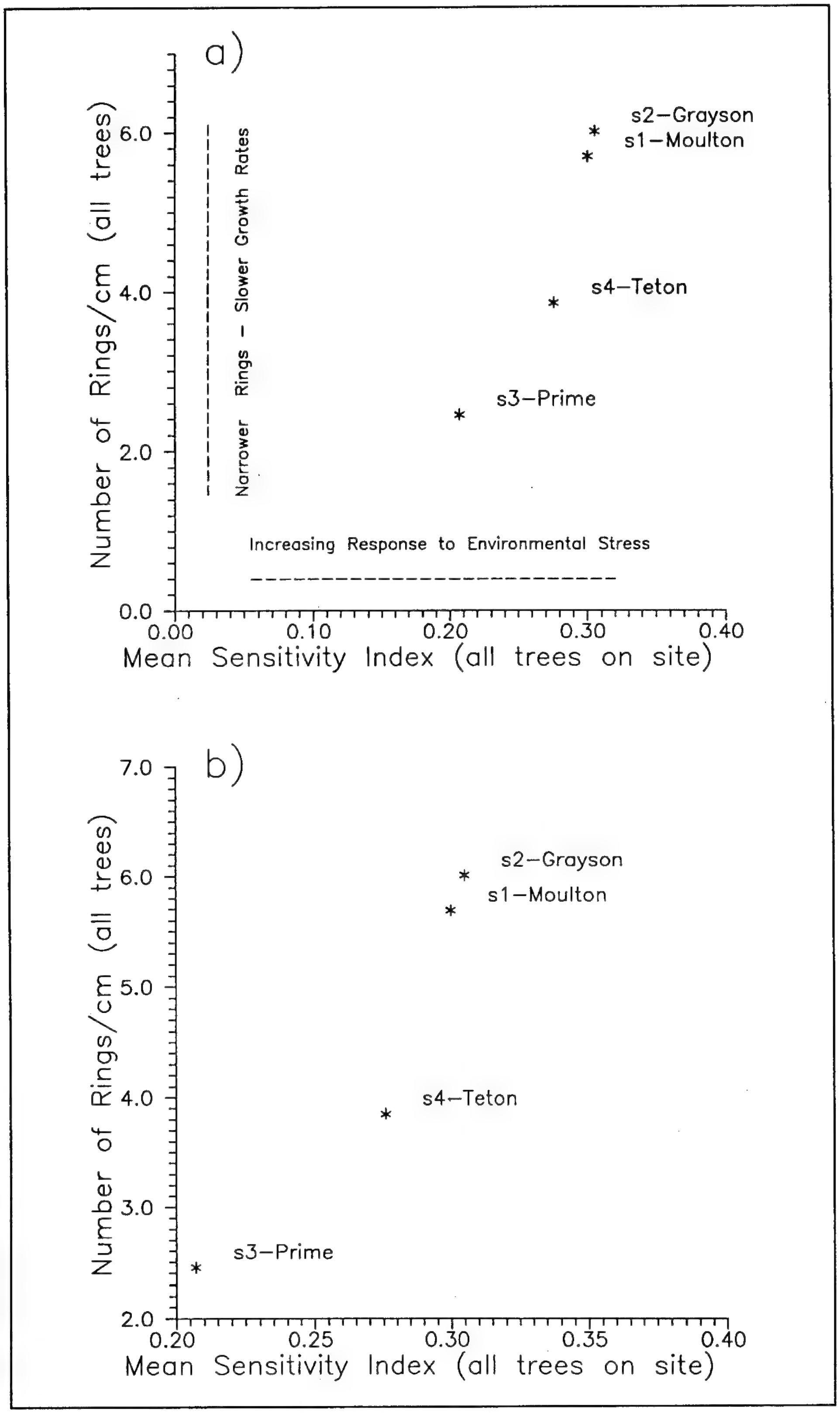

Figure 21. Bivariate plots of mean sensitivity and Rcm for all trees from each site

fitting exponential function to the two clusters. The more variable cottonwood growth is clearly indicated.

Finally, in Figures 24a and b, the species MSI are plotted against Rcm for trees 20 to 30 years old (this being one of the brackets with more complete samples for all sites). The trends mentioned above are depicted graphically in Figure 24a, and it can be seen that Site 1 (Moulton) firs were more stressed environmentally and had narrower rings than Site 4 (Teton), but that Sites 1 and 4 were more similar to each other in general than either site was to Site 2 (Grayson). This is not generally the case, with the underlying pattern in many of the analyses being the similarity of Sites 1 and 2, and Site 4 (Teton) being intermediate or somewhat more similar to Site 3 (Prime).

Figure 24b shows that cottonwoods had the lowest growth rates at Site 1 (Moulton) and Site 2 (Grayson), while growth for 20- to 30-year trees was very comparable at Site 3 (Prime) and Site 4 (Teton). However, another clear distinction between Sites 3 and 4 can be seen with regard to their position along the x (MSI) axis. Site 3 (Prime) clearly has been much less affected by environmental stress. However, this also must mean that Site 4 (Teton) has some years with growth rates much higher than at Site 3 (Prime) to achieve a higher MSI but have the same average Rcm.

Summary of Site Rankings

A reasonably comprehensive review of growth form, ring variability and width, and Rcm produces some consistent results, but also enough crosscutting site contexts and age/date brackets to produce enough diversity to make the information difficult to "internalize." This is especially the case because of three main factors:

a. Overall rankings might shift by one position between analysis (a site might rank first in growth rate for one species but second for another).

b. The scattering of "missing values" where an age/date bracket was not available for a given species.

c. Basic 1 through 4 rankings do not express the actual magnitude of differences between the four sites (e.g., sites with a ranking of 1 and 2 could have a MRW that was either very close together or relatively far apart in terms of actual millimeters of ring width).

Therefore, as the analysis progressed, the team experimented with a variety of methods to summarize and make more precise the multitude of possible site rankings. While basic rankings do not allow for differences in magnitude, a combined summary could have the effect of blending sampling error, age effects, and other factors that make for small changes in analytical results, and would have the ultimate effect of standardizing at least some of the hidden differences in magnitude. A ranking summary is included in Table 8.

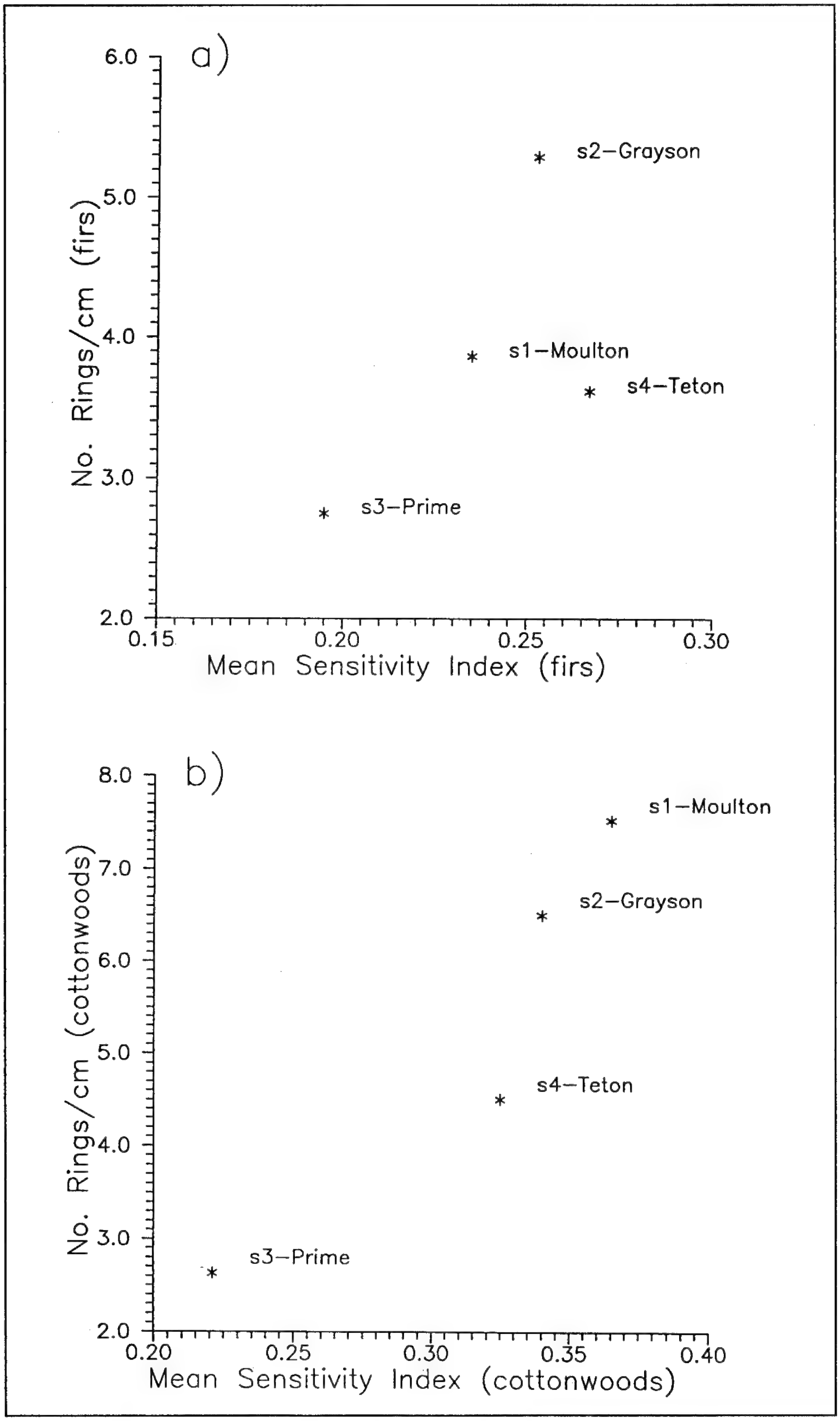

Figure 22. Bivariate plots of mean sensitivity and Rcm for firs and cottonwoods

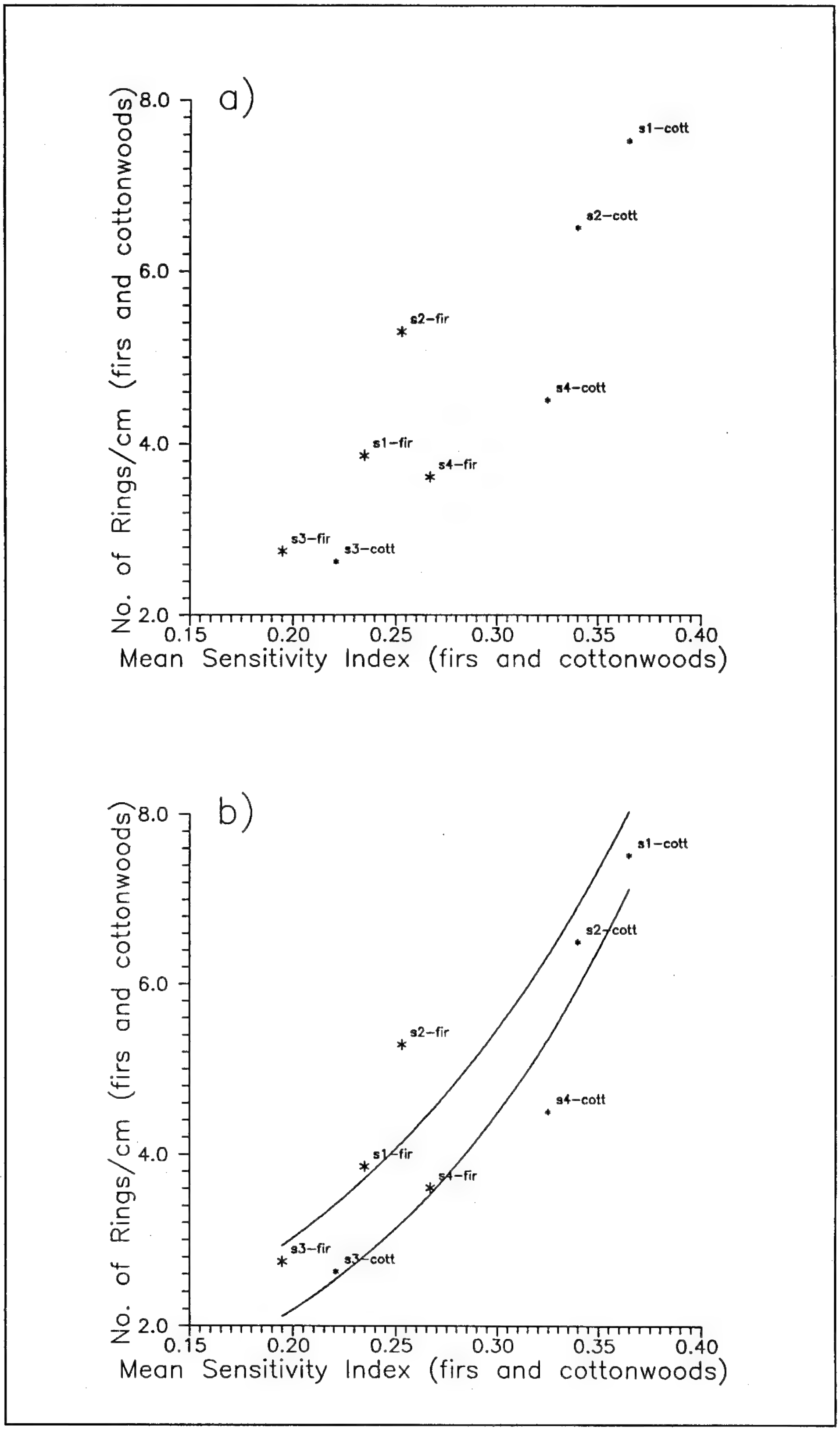

Figure 23. Bivariate plots of mean sensitivity and Rcm combining firs and cottonwoods

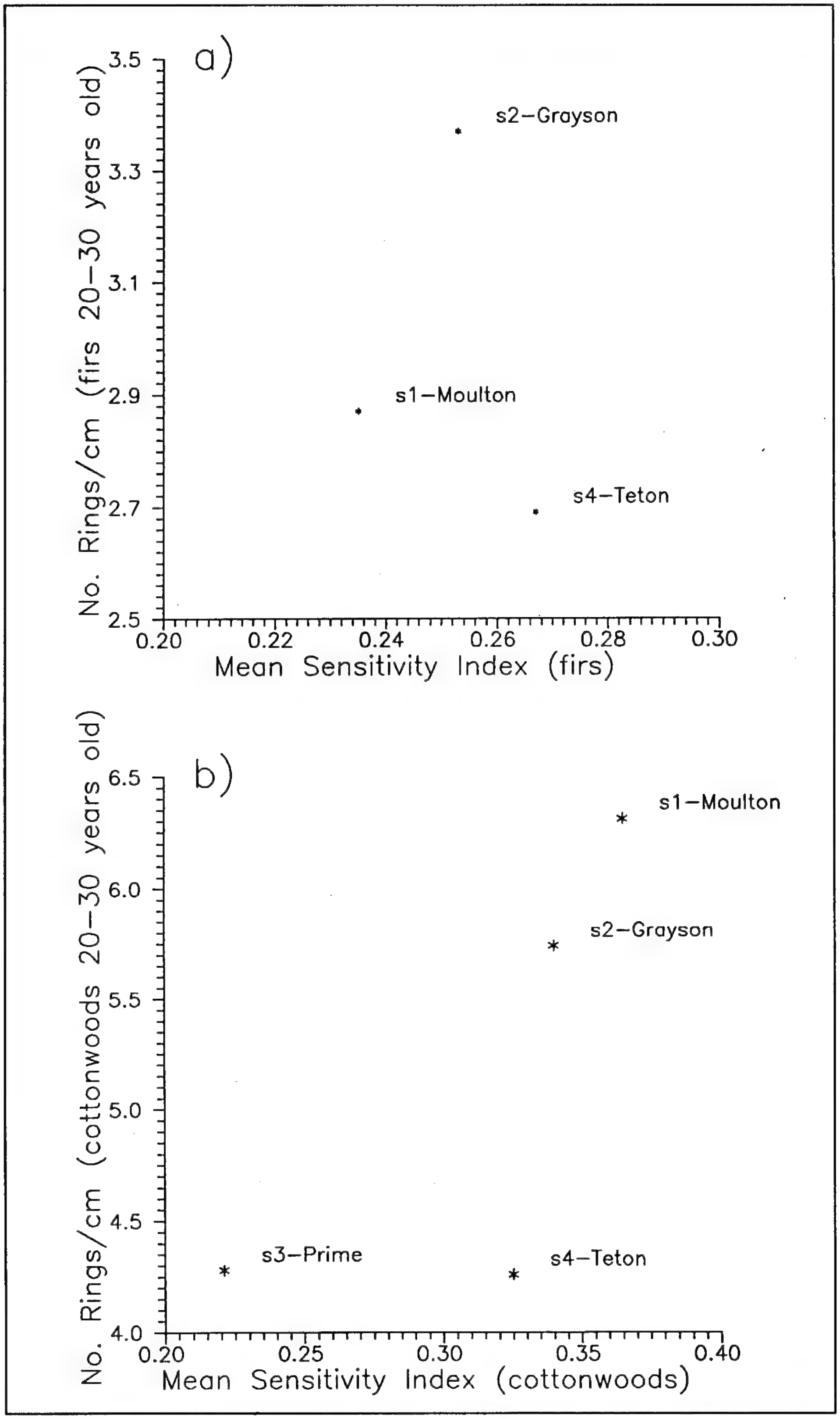

Figure 24. Bivariate plots of mean sensitivity and Rcm for fir and cottonwood growth while 20 to 30 years old

Table 8
Comparison of Site Growth-Rate Rankings

All Species-Specific Analytical Techniques				
	Site 1	**Site 2**	**Site 3**	**Site 4**
Mean Ring Width				
Firs	3	4	1	2
Pines	-	-	1	2
Cottonwoods	4	3	1	2
Bracket 1[1]				
Firs	1	2	-	-
Cottonwoods	2	3	-	1
Bracket 2[2]				
Firs	2	3	-	1
Cottonwoods	4	3	2	1
Bracket 3[3]				
Firs	-	3	1	2
Pines	-	-	1	2
Cottonwoods	3	-	1	2
Mean Rcm				2
Firs	3	4	1	2
Pines	-	-	1	2
Cottonwoods	4	3	1	
Bracket 1				
Firs	1	2	-	-
Cottonwoods	2	3	-	1
Bracket 2				
Firs	2	3	-	1
Cottonwoods	4	3	2	1
Bracket 3				
Firs	-	3	1	2
Pines	-	-	1	2
Cottonwoods	3	-	1	2
Basic Rank	3	4	1	2
Average Bank	2.71	3.00	1.14	1.67
All Analysis Utilizing Refined Age/Date Brackets				
Average Bank	2.4	2.8	1.25	1.5
Ranking Summary for Only Age/Date Brackets with All Sites Represented				
Rank Sum	22	20	8	10
Average Rank Sum	3.67	3.33	1.33	1.67

(all ranking by position where lower numbers = higher growth rates/wider rings)

[1] Comparison of oldest trees, bracket 1950 to 1970.
[2] Comparison of medium-aged trees, bracket 20 to 30 years old.
[3] Comparison of youngest trees, all years.

A site was assigned the rank of 1 to 4 for each type of analysis, with the lowest number representing the highest growth rate for that analysis. A "1" means that the site was in first position or had the highest rate of growth. Age/date brackets for MRW are indicated in this table. They were not used in the above analysis of MRW because they are not as standardized as Rcm and, therefore, provided redundant information.

Summarizing all date/age brackets per species results in the following overall modal growth-rate tendency:

a. Site 3 (Prime).

b. Site 4 (Teton).

c. Site 1 (Moulton).

d. Site 2 (Grayson).

More interesting was the computing of an average ranking, not affected by missing values since the average was calculated by dividing by the actual number of brackets available for a given species. The mean rank statistic emphasized the way the sites make two basic clusters more than some of the analyses did.

a. 1.14 - Site 3 (Prime).

b. 1.67 - Site 4 (Teton).

c. 2.71 - Site 1 (Moulton).

d. 3.00 - Site 2 (Grayson).

Finally, some of the more refined age/date brackets were used for a more definitive summary. In other words, this summary computes the same sort of average, i.e., according to the actual number of age/date brackets obtained, while also excluding all more generalized data such as "all first on site" or "all cottonwoods" indices, etc. The average ranking for all analyses that used only age/date brackets arrayed the sites as follows:

a. 1.25 - Site 3 (Prime).

b. 1.50 - Site 4 (Teton).

c. 2.40 - Site 1 (Moulton).

d. 2.80 - Site 2 (Grayson).

The final summary was based on the six brackets where all stations were represented (MRW and Rcm for all firs, all cottonwoods, and medium-aged

cottonwoods). With all stations represented, both a rank sum statistic based on adding all ranking, and an average rank could be computed. The rank sum statistic was computed as:

a. 8 - Site 3 (Prime).

b. 10 - Site 4 (Teton).

c. 20 - Site 1 (Moulton).

d. 22 - Site 2 (Grayson).

The average rank sum statistic was determined to be:

a. 1.33 - Site 3 (Prime).

b. 1.67 - Site 4 (Teton).

c. 3.67 - Site 1 (Moulton).

d. 3.33 - Site 2 (Grayson).

It is important to note that while a specific analysis here and there could swap rankings 1 with 2 and so on, the highest growth rates were at the leveed/disturbed Prime site, followed by the unleveed/undisturbed Teton Park Site, with the lowest rates at the leveed/grazed Moulton Site and the leveed/undisturbed Teton Park Site, with the lowest rates at the leveed/grazed Moulton Site and the leveed/undisturbed Grayson Site. Also emphasized was a pattern where there is a higher and lower cluster, rather than a continuum of growth rates. This pattern where Sites 3 and 4 formed a subcluster, as did Sites 1 and 2, emerged in only some of the most basic analyses, but it was consistent in the ranking summary (Table 8).

Thus, as discussed above, summed and average ranking indices had the effect of standardizing basic rankings, allowing the effect of actual differences in magnitude to emerge. When these trends were based on the refined brackets so that age effects and other sample biases had been removed, it should be clear that the growth contexts of the individual study sites should be the only major contributor to the final solution.

Statistical Evaluation of Growth Rates

Although the consistency of the results was obvious by this juncture, a basic statistical evaluation was performed using several MiniTab routines. Differences based on sample sizes totalling in the hundreds and thousands (ring measurements for a species per site) will have extremely high degrees of freedom in a statistical sense and may be the sort where continued statistical evaluation may be superfluous. Conversely, minute differences of as little as a

few tenths of a millimeter in some cases are such that an evaluation of probabilities can lend confidence, or caution, to an interpretation.

Other limitations need to be mentioned, such as the selection of tests based on an assumption of independent samples, which might not be completely accurate. It could be argued that endogeneous and exogenous factors were outside, i.e., independent causes affecting each individual tree. In the real world, this is not strictly the case if the canopy of the cottonwoods sampled was a factor in the growth rate of nearby fir saplings sampled. However, the assumption of independence was maintained, and variances were assumed to be inequal and were not pooled.

Pairwise comparison

Given all of this, it was decided that the samples were robust enough that basic tests of the statistical null hypotheses of the MRW were the same at each site. The results of a series of pair-wise t-tests of means are summarized in Table 9. A low p value indicates that the null hypothesis can be rejected with low risk of error and that the alternate hypothesis proposing a difference in MRW and mean Rcm can be accepted.

Both one-tailed tests (e.g., that MRW from Site 2 was specifically larger that MRW for Site 1) and two-tailed tests were used (i.e., that the mean of the one site was slightly different, whether larger or smaller). The one-tailed test computes the region of rejection for only one side of the probability distribution and will decrease the p value somewhat, so the results of the two-tailed test should be more conservative, i.e., the investigator would be more likely to accept the null hypothesis that the means are the same.

The results of the pair-wise analysis of species-specific age/date brackets show that almost all site differences were statistically significant. The confidence level assigned was 99 percent; thus, an acceptable risk of < 0.01 was established. A p value of 0.0000 in Table 9 indicates that the probability of being wrong in determining that the site means are different was less than the program's cutoff for decimal points (e.g., 0.0000 indicates an even smaller value such as 0.000005). Of 40 comparisons based on species/site and age/date bracket comparisons, only four pairwise differences were not significant; two or three more were marginal. It appears that medium-aged firs (Sites 1 and 3) and medium-aged cottonwoods (Sites 3 and 4) had slightly different but similar enough growth to cause a re-examination of the results from the other analysis. In the latter case, this fits well within the pattern of faster growth noted at both sites; while in the former case, higher fir growth rates relative to cottonwood had been noted for Site 1.

Table 9
Significance Values for Pairwise T-Test Evaluation of Mean Ring Size

	One-tailed p value	Two-tailed p value	T value
Subalpine Fir			
Oldest Trees			
Sites 1 and 2	0.0000	0.0000	10.19
Medium-Aged Trees			
Sites 1 and 2	0.0055	0.011	2.61
Sites 2 and 3	0.0049	0.0098	-2.74
Sites 1 and 3	0.21	0.41	-0.83
Youngest Trees			
Sites 2 and 3	0.0000	0.0000	-8.18
Sites 3 and 4	0.0001	0.0002	3.81
Sites 2 and 4	0.0000	0.0000	-4.90
Lodgepole Pine			
Youngest Trees			
Sites 3 and 4	0.0000	0.0000	11.52
Narrowleaf and Black Cottonwood			
Oldest Trees			
Sites 1 and 2	0.0096	0.019	2.36
Sites 2 and 4	0.0000	0.0000	-10.28
Sites 1 and 4	0.0000	0.0000	-5.30
Medium-Aged Trees			
Sites 1 and 2	0.079	0.16	-1.42
Sites 2 and 3	0.0000	0.0000	-4.32
Sites 3 and 4	0.47	0.94	-0.07
Sites 1 and 3	0.0000	0.0000	-4.88
Sites 1 and 4	0.0000	0.0000	-5.16
Sites 2 and 4	0.0000	0.0000	-4.63
Youngest Trees			
Sites 1 and 3	0.0001	0.0002	-3.97
Sites 3 and 4	0.0013	0.0027	3.10
Sites 1 and 4	0.076	0.15	-1.45

Analysis of variance

Also evaluated were MRW using the Minitab Oneway Analysis of Variance (ANOVA) based on sum-of-squares to calculate an f-statistic. The results are summarized in Table 10. Detailed output including sum-of-squares values and other information is in an unpublished report at the U.S. Army Engineer Waterways Experiment Station. Unlike the pairwise comparison, ANOVA uses the sum-of-squares computation to compare all site means at the same time. The analysis was performed for species-specific date/age brackets where appropriate site samples existed. A multiple ANOVA to determine which site means contributed the most to the comparison was not attempted.

Table 10
Significance Values for One-way Analysis of Variance (ANOVA) Evaluation of Mean Ring Size

	F value	P value
Subalpine firs		
Oldest trees (years 1950-1970) Sites 1, 2	101.43	0.000
Medium age trees (20-30 years old) Sites 1, 2, 4	2.87	0.061
Youngest trees (all years) Sites 2, 3, 4	21.07	0.000
Lodgepole pines		
Youngest trees (all years) Sites 3, 4	134.88	0.000
Narrowleaf and black cottonwoods		
Oldest Trees (years 1950-1970; start year before 1960) Sites 1, 2, 4	49.15	0.000
Medium Aged Trees (all trees in sample when 20-30 years old) Sites 1, 2, 3, 4	15.04	0.000
Youngest trees (all years) Sites 1, 3, 4	7.45	0.001

The ANOVA results show again that with the multiple site comparisons all sites had significantly different MRW, if a marginally significant 0.06 p value for the comparison of medium-aged firs from Sites 1, 2, 4 is allowed.

Using the size of the f-statistic as a rough indicator, it is apparent that comparisons of oldest trees and youngest trees tend to make up the strongest departures between the sites. Use of the statistic in this way is not necessarily accepted procedure in classical statistics where only acceptance/rejection of the null hypothesis is the desired outcome. However, the degree of overlap in the 95 percent confidence interval bar graphs tend to bear out this suggestion.

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13. ABSTRACT *(Maximum 200 words)*

This is a dendrochronological study of tree-growth rates along the Snake River floodplain in Jackson Hole, Wyoming. The study involved collecting, curing, and analyzing 115 measurable radii from 56 trees in four study sites. The sites are a representative set of Snake River floodplain contexts, organized around a continuum of different amounts of human and natural effects on the floodplain ecosystem. From these analyses, information concerning tree-growth rates under varying floodplain conditions, such as areas with flood control levees versus no levees or disturbed by flooding or grazing versus no recent disturbance, was examined. The study also involved the design and construction of a new IBM-compatible computerized measuring system, along with programming new software and obtaining or refining existing software.

The results reveal a clear and statistically significant difference in tree growth at the four study site contexts. A stand age-effect and related successional processes contributed to the growth rates seen, as did competition from developing canopy coverage and understory density. These are in turn greatly affected by the establishment, or lack, of levees, and by livestock grazing and other disturbances that accrue after a levee has been built. Clear differences

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exist between evergreen and cottonwood species, with cottonwoods being more sensitive to climate variability and disturbance. A growth rate differential as high as 60 to 80 percent between the highest and lowest growth site was discovered in some brackets, and never less than 20 to 40 percent in most comparable brackets.